Introduction

When two conflicting images are presented to the eyes, the images rival, that is, the two images will alternate in visibility every few seconds. The images upon the retinae do not change, but the percept does, hence, binocular rivalry has been seen as a tool to explore the neuronal correlates of conscious perceptions. Many models of binocular rivalry have been proposed, most focusing on either top-down or bottom-up processes to explain the phenomenon. In the current paper, a neural network architecture is suggested in which such restraints are not imposed; rather, it is proposed that rivalry can occur both early and late in visual processing, depending on the complexity of the stimuli. A computer implementation of the model will allow simulation results to be compared with well-known characteristics of binocular rivalry. To clarify the motivation for the current model, a brief overview of the literature on binocular rivalry will be given.

The phenomenon of binocular rivalry was documented as early as 1760 by Dutour (O'Shea, 1999). In the late 19th and early 20th century, it was argued by Hermann Ludwig Ferdinand von Helmholtz, William James, and Charles Sherrington that *what was rivalling* in binocular rivalry was *the stimuli*, that is, it was argued that rivalry was a high-level process where two fully processed interpretations of the retinal images competed for conscious attention. Levelt (1965) introduced the idea that rivalry was a low-level process, that rivalry was between the eyes, not the stimuli, and that what was rivalling was image primitives. The discovery by Fox and Rasche (1969) that an image is suppressed for shorter time periods as its contrast increases, prompted Blake to look for the threshold of contrast for which rivalry will occur

(Blake, 1977). Such a threshold was found, and to explain these and other findings, Blake (1989) posited the existence of binocular and monocular neurons. That is, it was proposed that there are neurons that receive excitatory input from the left eye, neurons that receive excitatory input from the right eye, and neurons that receive excitatory input from both eyes. Rivalry was seen as a result of "reciprocal inhibition between feature-detecting neurons in early vision" (Blake, 2001, p. 27).

Both "stimulus rivalry" and "eye" rivalry are now used as explanatory models. Evidence exists to support both theories, but the evidence seems contradictory. Blake, Westendorf and Overton (1980) showed that if the two stimuli are swapped just as one has become dominant, the dominant stimuli will be rendered invisible, and the suppressed one will be seen. This result supports the notion of "eye" rivalry. Counter to this finding, Logothetis, Leopold, and Sheinberg (1996) found that if both rival targets were flickered at 18 Hz and exchanged between the two eyes every 333 ms, observers would still report dominance of one stimuli lasting for seconds, indicating that rivalry happens between stimuli, not between the eyes. To investigate the generality of this finding, Lee and Blake (1999) examined rivalry at slower exchange rates and lower spatial frequency gratings than those used by Logothetis et al. (1996), and found that "stimulus rivalry" was dependent on the 18 Hz flicker. Nevertheless, still more evidence for "stimulus rivalry" was reported by Logothetis and co-workers. Whereas activity of neurons in V1 does not seem to correlate strongly with perceived (i.e., dominant) stimulus (Leopold and Logothetis, 1996), neurons in temporal areas thought to be involved in complex object recognition seem to be in synchrony with the monkey's reports of stimuli dominance (Sheinberg and Logothetis, 1997). These findings have prompted Blake (2001) to argue that the neural substrates of rivalry

might need to be rethought. Clearly, the discrepancies between psychophysical studies and neurobiological evidence open the possibility for a third kind of model, where rivalry is not seen as occurring at any one place, but is rather spread out through the visual information processing systems of the brain.

It has been proposed that rivalry occur at multiple stages (Blake, 1995), or even that it is "an oversimplification to speak of rivalry 'occurring' at any one particular neural locus" (Blake, 2001, p. 32). Blake (2001) cites several brain imaging studies that seem to show that rivalry can be detected all through the visual system, with the traces of rivalry being stronger at the higher stages. Thus, in the current paper, a neural network architecture is suggested in which such restraints are not imposed; rather, the model will allow for rivalry both early and late in the visual processing. The aim of the study is to explore whether or not such a model can produce predictable outcomes consistent with well-known characteristics of binocular rivalry. It is hypothesised that rivalry will be found at several stages throughout the information processing, and that more complex stimuli will show more evidence of rivalry higher up in the processing "hierarchy."

Method

Apparatus

The simulated hybrid neural network will be programmed in C++ to allow the authors maximum flexibility in designing the network, and because such an implementation will run faster than any off-the-shelf software.

Procedure

The neural network will be of a modular design, that is, it will be designed in such a way that each part of the network is easily exchangeable, allowing for exploratory programming and quick testing of hypotheses.

The model will consist of four layers, each feeding into the next layer, but also receiving reciprocal connections from one, or more, higher layers (see Figure 1). Some lower layers also project to several higher layers. Each layer is a separate kind of network, corresponding to the kind of network found in wetware. The "eyes/Lateral Geniculate Nucleus (LGN)" is the input layer, and will consist of $i = 2 * (x * y)$ inputs; that is, the two eyes will receive images represented as pixels on a Cartesian plane. This structure sends its output to both the striate cortex (V1) and the extra striate layer (V+). Consistent with current neurobiological understanding, V1 will be a self-organising network comprised of both monocular and binocular neurons. That is, V1 will have an input layer with neurons that receive connections from either the left eye or the right eye, and a hidden layer that receives input from any number of these input neurons. V1 will be topographically organised. For simplicity, it will be assumed that about 50% of the neurons in V1 are binocular, and that the other 50% are split evenly between the two eyes (Figure 2). Output from the eyes/LGN to V1 will alternate between left and right eye information, mimicking ocular dominance columns (Figure 2). The massive divergence from the eyes/LGN to V1 implies that V1 will consist of more neurons than the earlier structure. In the present model, the number of neurons will be in the vicinity of $100 * i$. From V1 onwards, information is projected to the extra striate (V+). That is, the extra striate receives projections from

both the eye/LGN-structure, and V1. V+ will have a bigger proportion of binocular neurons than V1; about 70% is assumed. V+ will project to the IT area, which represents the more complex memory of the model. The IT area will therefore be implemented as a Sparse Distributed Memory (SDM), whereas the other areas will learn by a more Hebbian approach. Finally, the IT area projects back to the LGN, modulating its output.
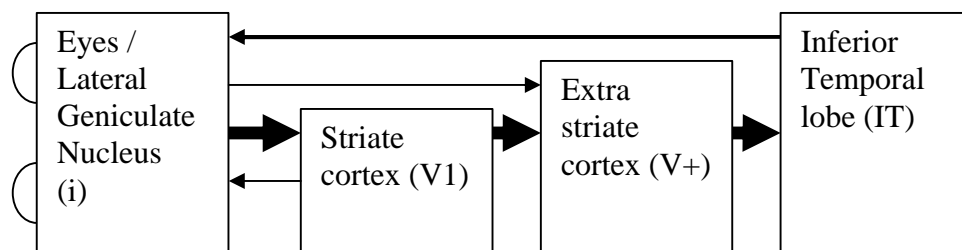
Figure 1. High-level view of the model. Thick arrows indicate main flow of information. Arrows from left to right represent information flowing "up" in the processing "hierarchy", and is assumed to get more complex as it goes. Arrows from right to left indicate recurrent connections. i sends information to both V1 and V+, and receives recurrent connections from both V1 and IT. Each layer is a separate kind of network corresponding to the type of network found in wetware.

The network will receive training from a data set with only consistent stimuli; that is, images presented to the two eyes will either be identical, or one of the images will be slightly shifted to one side. This should result in a network that "expects" non-rivalling stimuli. After training, testing will consist of presenting the network with some consistent and some inconsistent stimuli. At each "junction" (where output from

one layer becomes input for another, higher level), this output/input will be "tapped"

and analysed for rivalry.
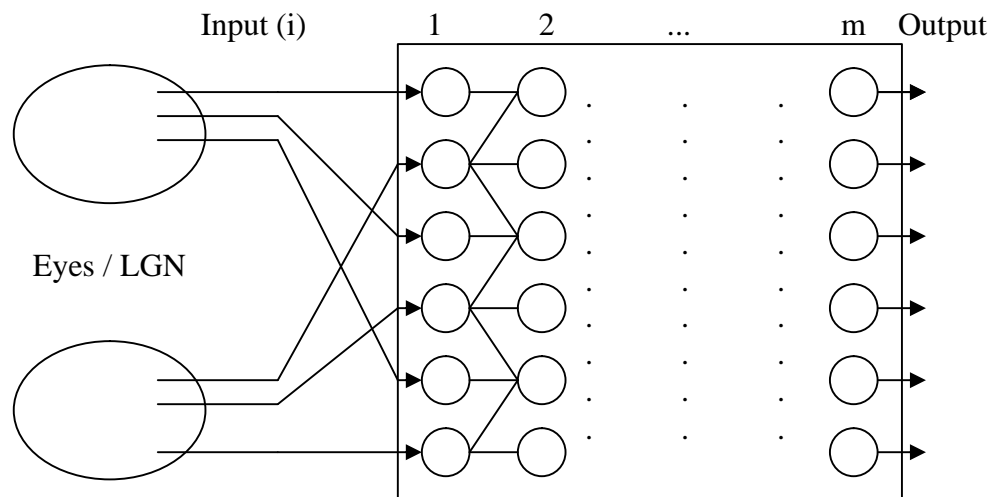
Figure 2. The eyes/LGN; here shown with i = 2*(3) for simplicity. This structure will

consist of approximately 50% binocular neurons. Sub-layer 1 is monocular; whereas

about half of the neurons of sub-layer 2 to m are binocular. Information flows from

left to right. Only excitatory connections are shown.

Results

Simulation results will be compared with well-known characteristics of binocular

rivalry (e.g., does higher contrast imply shorter suppression time). New in this study,

it will be seen if rivalry occurs at predicted junctions for simple and complex stimuli.

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