Neuromorphic model of Magnocellular and Parvocellular visual paths: spatial resolution

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Abstract. Physiological studies of the human retina show the existence of at least two visual information processing channels, the magnocellular and the parvocellular ones. Both have different spatial, temporal and chromatic features. This paper focuses on the different spatial resolution of these two channels. We propose a neuromorphic model, so that they match the retina’s physiology. Considering the Deutsch & Deutsch model (1992), we propose two configurations (one for each visual channel) of the connection between the retina’s different cell layers. The responses of the proposed model have similar behaviour to those of the visual cells: each channel has an optimum response corresponding to a given stimulus size which decreases for larger or smaller stimuli. This size is bigger for the magno path than for the parvo path and, in the end, both channels produce a magnifying of the borders of a stimulus.

Key words: magnocellular, parvocellular, retina, excitation, inhibition.

1. Introduction
Considering spatial vision, two of the most well-known models are the feature detection model and the spatial filter model [1],[2]. The former consists in a hierarchical system in which the cortex cells are specialized in detecting certain features by means of the information provided by the cells in the lower layers. The second model is based on Fourier’s analysis. It states that there are different physiological channels through which information is transmitted. Their characteristic is the spatial frequency with which they are in tune. An object’s spatial frequency is the inverse of its angular size in degrees. For periodical stimuli, spatial frequency is expressed in cycles per degrees (c/d) and it represents the quantity of cycles present in the stimulus of a one-degree visual angle.

Research on physiology sheds light on the existence of at least two visual channels that process spatial information: the magnocellular and the parvocellular ones [3], [4], [5]. Both have different spatial, temporal and chromatic properties. In this case, we are interested in the spatial frequency response. The magno channel reacts better to low frequencies (e.g. at 2 c/d), while the parvo channel has a better response to higher spatial frequencies (e.g. 30 c/d).
The area where the photoreceptors are connected to a same ganglion cell is known as its receptive field. The receptive field of a ganglionar cell –whether it belongs to the Magno or the Parvo channel– has two concentric areas (centre-periphery) which respond differently to luminous stimulation [1]. If the cell’s response increases when the centre lights up and it decreases when the periphery is illuminated, then we are faced an ON-OFF configuration of the field (see figure 1). On the other hand, if the ganglionar exit decreases when the central area is lit and the exist signal increases when illuminating the periphery, we are in the presence of an OFF-ON receptive field.

![Diagram of receptive field](image1)

Fig. 1. Scheme of the receptive field of an ON-OFF ganglionar cell.

Within the neural models of spatial filters, Deutsch & Deutsch (1992) [6] have proposed a retina model made up of 4 layers of cells. They considered an only receptive field size composed of the central zone of a cone and an inhibitory zone of 5 cones (including the central area cone). In this model, the enhancement of the edges (luminance transition areas) of the stimuli can be appreciated due to the lateral interaction that takes place in the horizontal cell layer. On the other hand, Grossberg & Hong (2206) [7] put forward a mathematical model about how the visual system processes images and which goes beyond the retina. It aims at human lightness perception. They worked with ON-OFF fields and they shaped the centre with a 1-pixel filter and the periphery with filters of three different sizes.

In this article we present a neuromorphic model of the two visual channels of the retina, based on the Deutsch & Deutsch model. We propose a connection configuration of the different cell layers based on the two reception field sizes, with the sizes of the centres and periphery that correspond to the physiological data of the magnocellular and parvocellular visual paths. We thus hope to reproduce the physiological behaviour found in the retina’s visual cells, such as the effect of the spatial sum.

2. Materials and methods

2.1. The Deutsch & Deutsch model

Fig. 2, presents the retina model described in [6]. We can observe 4 neuron layers which carry out the retina image processing. The first layer is formed by the photoreceptors cones, which transform electrical energy into light energy. Equation (1) shows the cones’ output voltage, which follows a logarithmic comprehension behaviour and which imitates the light adaptation process of the human visual system.

\[
V_p = 16 + 5 \log \left( \frac{L_z}{L_z0} \right)
\] (1)
Where $V_p$ is the voltage produced in the cone cells (in mV), $L_z$ is the Light intensity of the stimulus and $L_{z0}$ is the average light intensity. The equation’s (1) validity is restricted to the cases where the relationship between the energy of the studied stimulus and the average energy of the visual scene is between 0.0408 and 24.5.

![Retina neural model](image)

**Fig. 2: Retina neural model** (Deutsch & Deutsch, 1992).

The second layer is made up of horizontal cells which carry out an average of the information of the nearby photoreceptors. The third layer is comprised of bipolar cells which process the excitation signal coming from the photoreceptors and from the horizontal cells’ inhibitory signal. A consequence of this connection is the enhancement of the limits from one stimulus to another. The proposed equation (2) shows function of horizontal cells.

$$V_h = V_p - 0.5 \times V_h$$  

Where $V_b$ is the voltage produced in bipolar cells and $V_h$ is the voltage produced in horizontal cells. The last layer is made up of ganglionar cells whose function is to transform the gradual potentials coming from bipolar cells in action potentials.

2.2. Adaptation of the model according to physiological results

In this paper, we have considered the average physiological data within a retinal area of 7 degrees centred in the fovea, which equals the area within a 2mm-diameter circle. Dacey & Petersen (1992) [8] measured the size of the receptive fields of Parasol and Midget ganglionar cells – belonging to the magnocellular path and the parvocellular path respectively – in different areas of the human retina. For the area considered in this article, the average size obtained for the Midgets was 10µm and 80 µm for the Parasols.

The receptive field centres also vary with eccentricity: they are small at the fovea, where visual acuity is maximal (approx. 1 minute) and they increase towards the periphery. The average size of the cones in the area considered is 2.5 µm (0.5°). Therefore, we adopted a 5 µm central zone for the Midgets (corresponding to 2 cones) and, with a proportion criterion, a 35 µm centre size for the
Parasols (corresponding to 14 cones). This centre-periphery size relation is in accordance with the data provided by Corner & Kaplan (1995) [9], who found that, in average, the centre in a primate’s retina is half the size of the periphery. The horizontal cells have an average size of 20 µm. The configuration of the parameters for the proposed model is indicated in table 1 and represented in figure 3.

| Channel       | Ganglion | Bipolar | Horizontal | Cone | Cone | Cone |
|---------------|----------|---------|------------|------|------|------|
| Parvo-Cellular| 1        | 1       | 1          | 2    | 4    |      |
| Magno-Cellular| 1        | 1       | 1          | 14   | 34   |      |

Considering these configuration, the stimulus size that produce an optimum response has a 40 c/d frequency for the Parvo, and a 5 c/d frequency for the Magnocellular visual path. These values coincide with the spatial frequency ranges found in different psychophysical and physiological experiments.

Fig. 3. Representation of the proposed configurations for the magnocellular (a) and parvocellular (b) channels. One can observe the number of cones in each channel and how they contribute to the ON and OFF signals.

3. Results

Once the model’s parameters are established according to physiological data, we will examine their response to different stimuli. On the first stage of the results, the behaviour of only one receptive field is studied and on the second stage we analyze the response of a group of receptive fields which are overlapped much like they are in the retina. The luminous pattern used is a pulse with a different width, of intensity 10 over a 0.1 intensity base (the units are relative).

3.1. Receptive field response

Figure 4 shows the receptive field response of a Parasol ganglionar cell (Magnocellular Path) when it is stimulated with pulsed of different sizes that are always centred in the ON area.
When the pulse width increases, the ON area exit increases proportionally, reaching a maximum response of 16 mV when the pulse is the size of 14 cones (covering the excitation zone completely) and maintaining that constant from then on. As the pulse increases, so does the stimulated portion of the OFF area and the level of the inhibitory signal. The latter does not suffer from saturation but rather reaches its maximal 16 mV value when the stimulus covers the receptive field entirely (32 cones). As a consequence of the behaviour of ON-OFF signals (squares and circles in figure 4), the response of the bipolar cell increases with the size of the stimulus until it reaches the 14 cones in the centre of the receptive field, after which it begins to decrease.

Figure 5 shows the results of the parvocellular receptive field. When the width of the pulse increases, so does the exit of the excitation area, reaching a maximal response when the pulse covers the ON area (2 cones) entirely. The inhibitory response suffers from a continuous increase as the width of the pulse rises and it can reach its maximum value when the receptive field is covert completely by the luminous signal. The bipolar cell shows its maximum value when the ON area totally lights up and it shows its minimum value when the whole OFF area is also illuminated. All these behaviours duplicate the ones found in physiological experiments on the retina [1].
We will now analyze the behavior of ‘n’ receptive fields involved in the processing of a spatial pulse of different widths.

Fig. 6. Response of a group of magnocellular receptive fields to different square stimuli. The ‘x’ axis represents the distance measured in receptive fields and the ‘y’ axis represents the response (in mV) of each receptive field. The different exits correspond to: Cones (full line), ON (dotted line), OFF (dashed line), Bipolar (dotted and dashed line).
The group of previous figures (figure 6) shows the bipolar cell exits, taking into account only the Magnocellular channel. When the width of the pulse broadens, there is an increase in the excitation and inhibitory signals. The excitation signal reached its maximal value of 16 mV when the pulse width covers the ON area entirely (the size of 14 cones), and then it remains stable as the pulse width continues to increase. When the pulse size matches with the ON area, we find the most significant difference between the ON signal (16mV) and the OFF signal (10mV) and, therefore, the maximal bipolar cell response. This difference later decreases for both smaller or larger pulse sizes. What can also be appreciated in the figure is the border enhancement produced for the cells in the parvocellular path, which are shown in figure 7.

![Graphs showing response from a group of parvocellular receptive fields to different sized square stimuli.](image)

Fig. 7. Response from a group of parvocellular receptive fields to different sized square stimuli. The ‘x’ axis represents the distance measured in the receptive fields and the ‘y’ axis represents the intensity (in mV) of each receptive field response. The different exits correspond to: Cones (full line), ON (dotted line), OFF (dashed line), Bipolar (dotted and dashed line).

### 4. Discussion and Conclusions
This work shows a configuration of the Magno and Parvocellular receptive fields with a physiological basis, which has a similar response to the measurements taken from visual cell responses. The stimulation of the ON area produces an increase of the ganglionar exit signal (through the bipolar cell), and the stimulation of the OFF area causes a decrease in the ganglionar cell response. Each
visual channel has a stimuli size for which the response is maximal; for sizes different to that one, the response decreases. The magno channel has a better response to low spatial frequencies while the parvo channel has a better response to high ones. On the other hand, the lateral interaction process makes the borders between the stimuli stand out, which facilitates its detection and, thereby, that of the diverse visual tasks.

The proposed configuration of the parameters presupposes that each ganglionar cell takes the exit of an only bipolar cell, while this one takes the one of an only horizontal cell. Despite the fact that when the receptive field is big, a ganglionar cell receives signals from more than one bipolar one, our model indirectly incorporates this fact when increasing the number of cones involved.

5. Future experiments
The model can be broadened by incorporating other characteristics from the magno and parvo paths, such as contrast gain.

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