Functional representations of retina channels via the RefineC retina simulator

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ABSTRACT: Following the recent discovery of the multichannel retinal processing as well as the multilayer CNN models of it, we are reporting results about some functional characteristics of three channels. In particular, we have been found qualitatively different maps of a video clip in the Local Edge Detector channel (LED), the Sluggish channel and the On transient channel. The impacts on making retinal prostheses chips are discussed.

1. Introduction

Since the discovery of the multichannel operational principles of the inner plexiform layer of a mammalian retina [3,9] and its accompanying CNN model [5,8], several studies have been made to uncover the functional representations of each channel. One major difficulty is that we do not know the decoding mechanisms.

Recently, this question has become not only an interesting open question, however, a striking one in view of the intensified research in making epiretinal prosthesis. In this case, the artificial input is placed on the ganglion cells, replacing the living retinal output.. Unfortunately, the understanding of the multichannel processing in the retina made the situation more complex, since it means that several outputs are to be generated and put to the optic nerve, in a precise manner. Even if we believe that due to the plasticity of the brain the pixels in a channel will accommodate to its role, the selection of the most important channels for the every day life is crucial.

In this paper we show, by using an advanced version of the freely available retina simulator REFINE-C (REceptive FIeld NEtwork Calculus), that three main components of a visual scene are decomposed in the Local Edge Detector (LED), the Sluggish, and a Transient channel, coding the edges, a kind of the inner parts of areas framed by edges, and some motion related effects. It is believed that these three components might code the outside world far better than a single LED channel.

2. Multichannel Retina

As it is known, the retina consists of several layers, which have different functions [1]. In order to model the function of the retina, measurements of the appropriate cells are necessary. Cells of the outer plexiform layer (OPL) can be measured for a long while and their function is well described [2]. On the other hand measuring the inner retinal cells, as well as the understanding of the operational principles of the whole retina is possible only recently [3].

Ten different functional channels of the rabbit inner retina were identified [3,10], all of them extract various spatial-temporal features of the input image flow. There is no sequence of images, it is a continuous flow in time and the signal value in each pixel depends on the inner retinal cells and receptors. The output cells of the retina are the ganglion cells coding the channels.

Although the ganglion spiking, the excitatory and inhibitory inputs were measured, for the sake of a better understanding of the retinal processing, a complete functional understanding of all channels is still needed.

3. Model of the Multichannel Retina using a Multilayer CNN

The CNN-UM architecture presented in [4] provides a suitable framework for implementing a programmable multilayer CNN retina model. This gives the hope to make an adjustable retina model chip.

The REFINE-C (REceptive FIeld NEtwork Calculus), simulator provides an experimental tool suitable for modeling different types of synapses [5], the receptive field as well as the output functions in the cell models. The horizontal spread of the neuronal signals can be regulated by the diffusion parameter of a CNN layer (denoted by a space constant). The time constants of each layer can also be adjusted (corresponding to the transmission speed of a neuron). In addition the inter-layer transmission weights are also defined.

	Cell name in [10]	Model in [5]	Examined in this paper
1	OFF Brisk Lin. 1.	Х	
2	OFF Brisk Transient	Х	
3	ON Brisk Transient Nonlinear	Х	X
4	ON Brisk Sustained	Х	
5	ON Sluggish	Х	X
6	Bistratified	Х	
7	ON LED	Х	X

Table 1Shows the cells identified in [10], the third column shows which of these were
modeled in [5] and the fourth column shows our present target channels.

In [5] a multilayer CNN model has been described for seven of the ten channels of the rabbit retina (in [3,10]). It also produced qualitatively the same patterns for the excitatory and inhibitory inputs of the ganglion cells to the "flashed square" input and to a natural scene. In this paper we investigate three channels of this model (see Table 1). We examine their responses on specific inputs and hereby investigate the main features of these three channels. The used models can be found in [6], they can be run using the retina simulator REFINE-C (see [7]).

4. Experimental Results

4.1 The Flashed-square response

In attempts that are aiming to clear up the functions of the individual retinal channels, we regard the flash-square as a basic experiment. The reasons for this are: 1) reliable to a great extent, since we also have the biological results, [3] 2) simple enough, but still shows the main characteristics of the channels in question.

The "flash-square" stimulus is simply a square that appears in a smooth gray background, remains there for one second, then disappears (See Figure 1 a.).[6]



Figure 1 a: The flashed square stimulus, resolution: 180 x 80 pixels

Since now only one retinal channel function is well analyzed, which highlights the edges of the objects, while eliminating the rest of the input visual stimulus. This is called "LED", which stands for "Local Edge Detector". Fig. 1 shows some frames of the OnLED channels response to the flash-square stimulus. (The entire video files can be found at [6] together with the avi files of the other experiments.)

Note that white color means the activation of the investigated cell (which are in this paper the ON cells) and black color means the corresponding opposite (OFF) cells response.



Figure 1: LED answer to the flashed square stimulus. b) The answer in the moment of the squares appearance. Only the edges are visible. c) is the persistent response: gives no output inside, but the edges are still emphasized. It is practically constant while the stimulus is present. d) shows the moment of the disappearance.

Although the Local Edge Detector channel contains a very important visual characteristic, this feature alone fairly not holds sufficient information about the visual scene.

4.2. Filling out the objects – the On Sluggish channel

This channel received its name after its main characteristic: the sustained response. This means, that - in contrast with the LED channel – the inside of the objects produces at least as strong answers as the edges. Also very important, that for rapid changes this channel does not react as violent as the Edge Detector.

For example the flash square evokes the answer depicted on Fig. 2. (For the sake of the better comparison we show exactly the same moments (frames) as can be seen on the images showing the LED response on Fig 1..)



Figure 2: The On Sluggish channel response to the flash square. a) The moment of the squares appearance – a tranquil, but clear response. The edges are less expressed.
b) The sustained response c) The moment of the disappearance – rapid changes evoke calmer answers.

This feature seemed to be suitable for "filling-out" the individual objects. In the interest of investigating this assumption, we examined the channels response on a realistic scene: a van passing by can be seen on Fig. 3, 4 and 5 - each with 128x128 pixels resolution.



Figure 3: Images of the original input. Entering (*a*), *filling out* (*b*) *and leaving*(*c*) *the scene.*

Fig. 4 shows the LED channels-, Fig. 5 shows the sluggish channels response for the appropriate frames.

These differences (between the LED and the sluggish channel) suggested that there might be some visual phenomena, which are undetectable for the LED but detectable for the sluggish process. One of these is when a part (or the entire) visual scene starts to change its shade smoothly, without boundaries or edges. This is imperceptible for the LED, but visible for the sluggish channel.







Figure 4: The LED answer on the van. a) The most intensive responses are on those points, where the edges are at the given moment. b) Notice, that this channel gives no observable difference between the shade of the van and the shade of the concrete.
c) Rapid changes (as disappearance) evoke intensive answers.



Figure 5: The On Sluggish channels answer on the van stimulus. **a**) No sharp edges. **b**) Notice that the van received its original shade. **c**) The answer holds out until the stimulus is present: vagueness cannot be observed.

The On Sluggish channel can follow the inner part of the object much better (Fig. 5).

4.3. Emphasizing motion – the On Transient channel

As the name suggests, this channels main feature is its transient response. It seems to give a very fast answer to any kind of spatio-temporal change – in other words: motion in the visual scene. A typical attribute of the transient channel is its ability to filter out the moving

parts of the scene among the motionless regions. These immobile sections seem to trigger no response of this channel. Fig. 6 shows the On Transient channels response to the flash square:



Figure 6: On Transient channels response on the flash square. **a**) The channel gives a vigorous answer in the moment of the objects appearance – sensitiveness to changes, similar to LED. **b**) shows the sustained response. This frame shows the most important difference between the LED and the transient channel. While LEDs sustained response for the flash square is its edges, transient gives no answer for motionless stimulus, even if it has sharp edges. **c**) The moment of the objects disappearance – strong answers for changes.

In order to investigate this effect on an every-day scene, we can analyze the stimulus depicting the passing-by van on Fig. 7. (This stimulus was already investigated from the LED and the Sluggish channels viewpoints on Fig. 4 and 5.)







Figure 7: On Transient channels response on the van passing by. The original input is depicted on Fig. 3. a) entering the scene b) filling out the scene c) leaving the scene.

Note the most important difference between the LED and the transient output: all unmoved parts of the stimulus are ignored: e.g. the signs (white stripes) from the concrete or the shoulder. For stressing this difference we put four typical frames next to each other on Fig. 8.



Figure 8: The back of the same van as can be seen on Fig. 3, 4, 5, and 10 – almost leaving the scene. a) the original input b) LED answer c) On Transient response d) On sluggish answer

On the flashed square responses we saw that the LED channel shows the frames of the objects (Fig. 1), the Sluggish channel gives a slow response for the whole square (Fig. 2) while the Transient gives answer only at the moments of flashing (Fig. 6).

The results on real scene were similar: LED channel enhanced the van's edges (Fig. 4), the transient channel filtered out the moving parts - which is consistent with the fact that it gives no sustained response for the unmoving regions; (Fig. 7) and the sluggish channel showed the interior parts of the car (Fig. 5).

5. Conclusion

The three main functional representations identified in the paper will be important to design a more appropriate retinal simulator. Further studies are needed to uncover the function of other channels as well as to prove these functions more rigorously and in more details.

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