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A neural model of feature attention in motion perception

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Abstract

We utilize a model of motion perception to link a physiological study of feature attention in cortical motion processing to a psychophysical experiment of motion perception. We explain effects of feature attention by modulatory excitation of neural activity patterns in a framework of biased competition. Our model allows us to qualitatively replicate physiological data concerning attentional modulation and to generate model behavior in a decision experiment that is consistent with psychophysical observations. Furthermore, our investigation makes predictions for future psychophysical experiments.

Keywords: Feature attention; Biased competition; Motion perception; Neural modeling

1. Introduction

Cortical motion processing is confronted with the problem of reliably estimating motion cues and to integrate them into consistent object related interpretations. Processes of attention help to increase the separation of localized features in order to group them together forming coherent object motions. In this work we build upon and further extend a neural model of cortical motion perception to link the outcome of experimental studies resulting from different investigations. Our studies combine experimental evidence concerning feature attention from electrophysiological and psychophysical observations. The proposed model makes further testable predictions that can be verified in future experiments.

1.1. Feature attention

Feature-based attention in early vision describes the deployment of attentional load to a specific feature irrespective of its spatial location, such as, e.g., motion direction (Martinez-Trujillo and Treue, 2004; Treue and Martinez-Trujillo, 1999) or orientation (Reynolds and Chelazzi, 2004). This type of attention selection is distinguished from spatial, or location-based, attention where information is expected at some location irrelevant of the feature and from object-based attention that is assumed to operate on chunks of already grouped features that form individual objects (Blaser et al., 2000). In this work we focus on feature attention.[2] In the following we outline two experimental studies, which investigate the effect of feature attention in motion perception.

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[2] Furthermore, our modeling framework also allows spatial attention to be included (not further investigated in this paper).

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1.2. Relevant experimental studies

It has recently been demonstrated by Martinez-Trujillo and Treue (2004) that in area MT of the macaque cell responses are modulated by feature-based mechanisms of attention. The authors evaluated cell responses to different directions of motion with different configurations of feature attention: (1) no attention to any specific motion; (2) attention towards the velocity that is preferred by the investigated cell; (3) attention towards the presented velocity. These conditions lead to the following key observations:

- For the experimental condition with feature attention towards the preferred direction of the observed cell an increased response was observed compared to the condition without attention independently of the presented motion pattern.
- When attention was directed to the presented motion two cases have to be distinguished: (1) an increased response of the investigated cell was observed compared to the condition without attention when the presented motion pattern was identical or similar to the preferred motion of the observed cell; (2) a decreased response was observed, on the other hand, when the direction of motion was very dissimilar to the preferred direction of motion of the observed cell.

A quantitative evaluation of their data showed that investigated cells are modulated by feature attention. Consistently, in the presence of modulatory feature attention towards the preferred direction of motion the shape of the cells' tuning curves did not significantly change.

The psychophysical study of Felisberti and Zanker (2005) demonstrated that attention significantly enhances the ability of humans to detect motion in transparent motion patterns. For a given number of transparent layers of motion, the authors compared the threshold at which a specific motion can reliably be detected for different conditions of feature attention. The experiments utilized an alternative forced choice task in which the observers had to decide about the presence or absence of a specific direction of motion. In one condition, the subjects were not informed about the motion direction prior to stimulus presentation, whereas in the other condition they were. This additional information guides the feature attention. The obtained results show an increased threshold (indicating more distinguishable transparent layers) when attention was directed to the direction of interest.

1.3. Modeling approach and outline of this work

In the next section we outline the main features of our model. First, we present an introductory example processing a motion sequence demonstrating the effect of feature attention. Then, systematic computational simulations are presented for a set of stimuli with moving random dots containing motion in different directions. These results are related to the experimental data presented in Martinez-Trujillo and Treue (2004) and Felisberti and Zanker (2005). Our simulations suggest an interpretation of the observed data in the framework of biased competition (Reynolds and Chelazzi, 2004), which is generated here by mechanisms of modulatory enhancement of activation (Eckhorn et al., 1990; Neumann and Sepp, 1999) and lateral competitive processing (Simoncelli and Heeger, 1998). The employed model is based on our previous work (Bayerl and Neumann, 2004) with the extension that global feature attention is included in the model dynamics to provide a top-down modulation signal.

2. Model

We model motion sensitive cells[3] in two areas of the dorsal visual stream, namely areas V1 and MT. In addition to these model areas we define a fixed task-related attentional signal that is fed into the integration scheme defined by bidirectional connections between model areas V1 and MT. The dynamics of each model area is defined by feedforward integration, lateral inhibition, and top-down feedback modulation (the equations and the parameters used for simulations are given in the Appendix A). The input to the model, and thus the input to model area V1, is generated by a correlation detector operating on band-pass filtered frames of the input sequence (see Appendix A).

2.1. Feedback and attentional modulation

Treue and Martinez-Trujillo suggested that attention modulates the activities in early motion areas (Martinez-Trujillo and Treue, 2004; see also Treue and Martinez-Trujillo, 1999). We thus model feature attention by utilizing a modulatory feedback signal to motion sensitive cells (see Fig. 1 for a sketch

[3] In our model all motion sensitive cells are tuned to speed as well as to motion direction (Bayerl and Neumann, 2004). Thus, each motion sensitive cell in our model is tuned to one specific "preferred velocity" or "preferred motion". Depending on the context or the experimental condition we will also use the term "preferred direction" if the preferred speed is not of interest.