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A Model of Position-Invariant, Optic Flow Pattern-Selective Cells

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Abstract

Two apparently inconsistent proposals for the functional architecture of MST cells exist, based either on a set of cardinal flow patterns [1] or a continuum of flow patterns [2]. A model is proposed by [1] that consists of excitatory and inhibitory subunits to support their architecture. Here, we used a neural network to show that a model of this type can be selective to the continuum of patterns [2]. We extended this model by introducing inhibitory connections between cells to account for the position-invariant characteristics of MST cells reported in [2].

References

[1] Duffy, C. J. and Wurtz, R. H. (1991b) Sensitivity of MST Neurons to Optic Flow Stimuli. II. Mechanisms of Response Selectivity Revealed by Small-Field Stimuli. *Journal of Neurophys.* **65(6)**, 1346-1359.

[2] Graziano, M. S. A., Andersen, R. A., and Snowden, R. J. (1994) Tuning of MST Neurons to Spiral Motion. *Journal of Neurosci.* **14(1)**, 54-67.

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Motivation

Recognition of optic flow patterns is useful in motion computing tasks such as determining *heading*. Duffy and Wurtz (1991b) have suggested that optic flow patterns are encoded by recognition of orthogonal patterns, such as *expansion*, *contraction*, *clockwise rotation* and *counter-clockwise rotation*. In contrast, Graziano et al. (1994) have suggested that optic flow patterns are encoded by position-invariant recognition of a continuum of patterns, which, in addition to the above, includes spiral patterns: *clockwise inward spiral* motion, *counter-clockwise inward spiral* motion, *clockwise outward spiral* motion, and *counter-clockwise outward spiral* motion. Is there a single mechanism that can account for both proposals? Is this mechanism position-invariant?

We implemented a model proposed by Duffy and Wurtz (1991b) and showed that this model can indeed implement units that are selective to all the patterns mentioned above. We focused on spiral patterns and developed a position-invariant model for these.

Technique

Model

We used 5x5 square visual fields in which optic flow patterns were represented (Figure 1). The patterns are those used by Wang (1995); however, we only used the expansion, contraction, rotation and spiral patterns (we did not use the large field planar motion patterns).

The inputs to the system were the responses of direction-selective units tuned to the four cardinal and four oblique directions. Duffy and Wurtz' (1991b) model of a pattern-selective unit uses an excitatory and an inhibitory subunit (Figure 2). The excitatory and inhibitory subunits respond preferentially to particular directions of motion within their receptive fields. The overall response of a subunit depends on the following parameters: its *center*, its *peak response* at the center, and the *extent* of its receptive field. The effect of the preferred motion on a subunit falls off exponentially from the center outward.

The output of the pattern-selective units was the response of the excitatory subunit minus the response of the inhibitory subunit.

Experiments

We studied the selectivity of the units by varying the parameters of the model, i.e., those of the subunits. We varied only the *preferred directions* and *center* of the subunits since empirical experiments showed that these parameters influenced the pattern-selectivity much more than the *peak response* (at the center) and *extent* of the subunit. We defined the *preferred* pattern of a unit as the pattern to which it responded most strongly.

We explored the position-invariance of units constructed using this model. We defined the *anti-preferred* pattern to be the pattern furthest away from the preferred pattern along the circular continuum formed by the patterns. To test the position-invariance of a unit, we presented the patterns in locations other than the center of its receptive field.

Results

We found that our implementation of the Duffy and Wurtz (1991b) model can produce units that are selective to each of the eight optic flow patterns. In general, units constructed using this model are *not* position-invariant. Figure 3 shows the responses of a unit that is selective to different patterns depending on the location of the pattern within its receptive field. However, a unit *can* be made position-invariant by connecting it in an opponent fashion to a unit that is selective to the anti-preferred pattern. Figure 4 shows the response of a unit selective to the anti-preferred pattern of the unit in Figure 3. Figure 5 shows the response of a unit that combines the output of the two units and whose response is position-invariant.

Discussion

We showed that an existing model of pattern-selective units (Duffy and Wurtz, 1991b) can account for a larger class of patterns. We extended this model to position-invariant units by introducing inhibitory connections among pattern-selective units. This extended model suggests that the different pattern-selective MST cells found by Duffy and Wurtz (1991a and 1991b) and Graziano et al. (1994) may have the same underlying mechanism. If we view the Duffy and Wurtz model as existing at one "layer" and the proposed extension at the next layer above, then this may suggest that Duffy and Wurtz and Graziano et al. were looking at different layers within MST. We believe that this model is biologically plausible because it is simple, and opponency is found in other parts of the visual system.

While we have shown that it is possible to construct units with position-invariant receptive fields, we have not suggested why this organization comes about. Future work will be to discover how such organization develops.

References

Duffy, C. J. and Wurtz, R. H. (1991a) Sensitivity of MST Neurons to Optic Flow Stimuli. I. A Continuum of Response Selectivity to Large-Field Stimuli. *Journal of Neurophys.* **65(6)**, 1329-1345.

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Graziano, M. S. A., Andersen, R. A., and Snowden, R. J. (1994) Tuning of MST Neurons to Spiral Motion. *Journal of Neurosci.* **14(1)**, 54-67.

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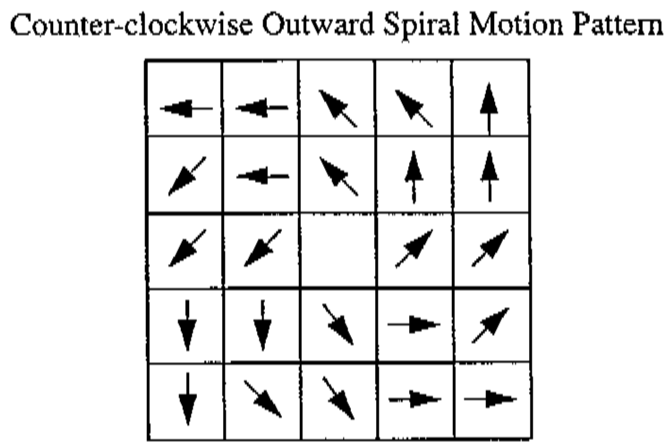

Figure 1. The representation of optic flow patterns used in our experiments. The optic flow pattern is represented by the local directional motions. This particular pattern is a counter-clockwise outward spiral. For the complete set of patterns used in these experiments, see Wang (1995).

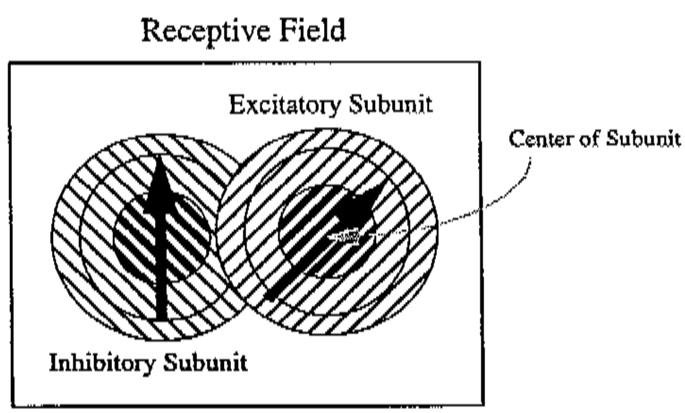

Figure 2. Example instance of Duffy and Wurtz' (1991b) model of an optic flow-selective unit. For the excitatory subunit, planar motion (e.g., upper right motion) contributes to the excitation of the unit; however, the contribution of this motion decreases with the distance from the center of the subunit. The situation is similar for the inhibitory subunit. The peak response of a subunit at its center and the extent of its receptive field may vary. The excitatory and inhibitory subunits may receive input from overlapping regions.

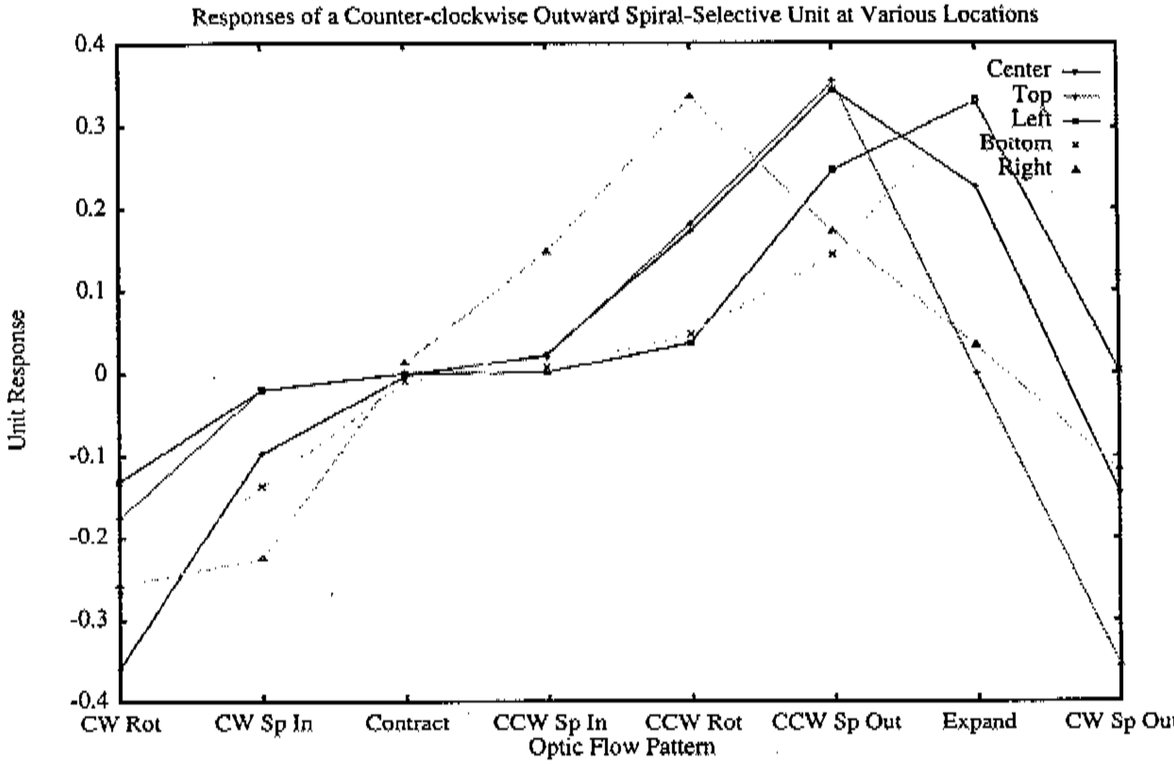

Figure 3. Responses of a counter-clockwise outward spiral-selective unit when patterns are presented at various locations. The units responses are not position-invariant.

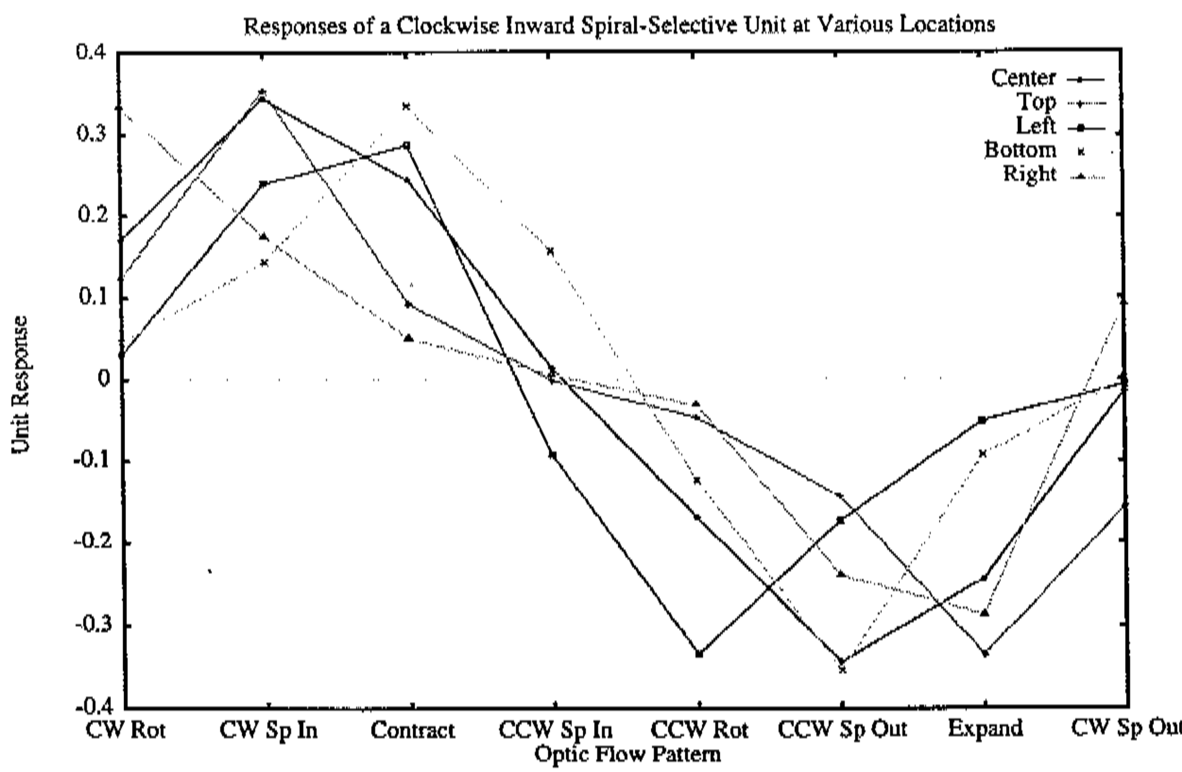

Figure 4. Responses of a clockwise inward spiral-selective unit when patterns are presented at various locations.

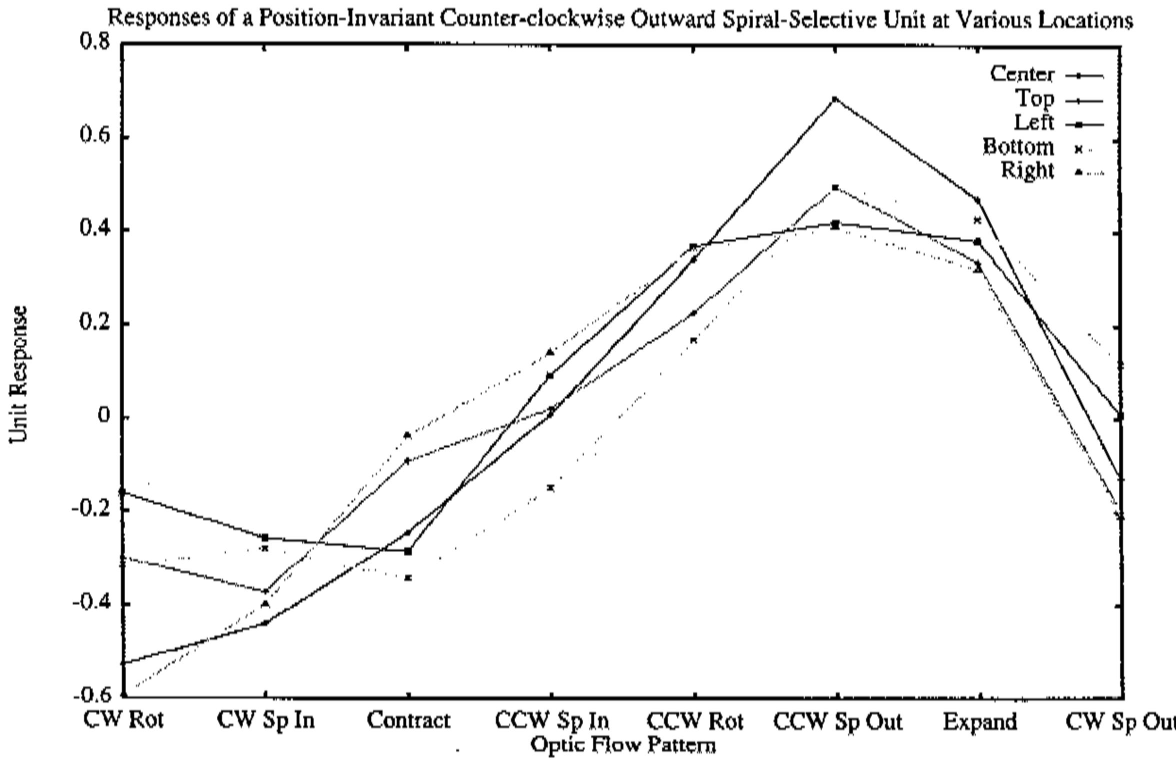

Figure 5. Responses of the position-invariant counter-clockwise outward spiral selective-unit when the patterns are presented at various locations.