The Gaussian Derivative model for spatial-temporal vision: II. Cortical data

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Abstract—Receptive fields of simple cells in the primate visual cortex were well fit in the space and time domains by the Gaussian Derivative (GD) model for spatio-temporal vision. All 23 fields in the data sample could be fit by one equation, varying only a single shape number and nine geometric transformation parameters. A difference-of-offset-Gaussians (DOOG) mechanism for the GD model also fit the data well. Other models tested did not fit the data as well as or as succinctly, or failed to converge on a unique solution, indicating over-parameterization. An efficient computational algorithm was found for the GD model which produced robust estimates of the direction and speed of moving objects in real scenes.

1. INTRODUCTION

We test whether the Gaussian Derivative (GD) spatio-temporal model described by Young et al. (2001) captures the spatial and motion characteristics of primate simple cell receptive fields. In particular, we determine whether the GD spatio-temporal model: (1) fits observed receptive field shapes in 3D space—time; and (2) describes the different ‘types’ of simple cell receptive fields in primate striate cortex.

The general equation for the spatio-temporal GD model for simple cell receptive fields is given in the companion paper (Young et al., 2001, their equation (1)). We found a simplified equation sufficed for fits to our current data sample:

\[ G_{n,p}(x', y', t') = g_n(x')g_0(y')g_p(t') \]  \hspace{1cm} n = 0, 1, 2, 3, 4, \hspace{1cm} p = 0, 1. \hspace{1cm} (1)

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Figure 1. ‘Periodic Table’ of GD spatio-temporal functions. The Gaussian derivatives given by equation (1) along the $x'$ axis, for $n = 0$ to $4$, are shown from left to right. The Gaussian derivatives given by equation (1) along the $t'$ axis, for $p = 0$ to $1$, are shown from bottom to top. Scales are in standard units: $1$ spatial unit $= \sigma_x$, $1$ time unit $= \sigma_t$. All functions are normalized to an absolute peak height of one. Contour lines are at $\pm 20$, $\pm 40$, $\pm 60$, $\pm 80\%$ of the peak height.

The GD numbers $n$ and $p$ specify the complete 3D spatio-temporal shape of a model receptive field. Figure 1A shows the three-dimensional iso-contours, and Fig. 1B shows the contour plots in space-time, for equation (1) for $n = 0$ to $4$, and $p = 0$ or $1$.

Section 2 presents the methods used in fitting the GD spatio-temporal model in equation (1) to physiological receptive field data from the primate brain. Section 3 presents the results of these fitting methods, showing that the GD spatio-temporal model describes both the static and motion properties of these receptive fields. Section 4 presents possible biological implementations of the GD spatio-temporal model, and the results of fits with other models. Section 5 shows results of a particularly efficient computer vision implementation that produced robust estimates of