Analysis of Brain Activation Patterns Using a 3-D Scale-Space Primal Sketch

Tony Lindeberg[1], **Pär Lidberg**[1,2], **Per Roland**[2]

[1]*Dept. of Numerical Analysis and Computing Science, KTH, S-100 44 Stockholm, Sweden*
[2]*Dept. of Neuroscience, Karolinska Institute, S-171 77 Solna, Sweden*

This paper presents a method for automatic determination of the spatial extent and the significance of rCBF changes.

A fundamental problem in functional brain imaging concerns how to group measured brain activation patterns into meaningful clusters. The cortical field activation hypothesis states that neurons in the cerebral cortex change their biochemical activity in large distinct ensembles, and in PET imaging one measures the changes in regional blood flow caused by increased metabolism in groups of activated neurons (Roland 1993). To determine automatically from a given PET image what should be regarded as natural populations of nerve cells has, however, turned out to be a non-trivial problem. The high noise level in the PET data results in a complex hierarchical structure of blobs of different size and amplitude, in which a key problem concerns how to determine which blobs should be regarded as significant and which ones as due to noise.

Traditional approaches for analysing such data sets involve the evaluation of statistical measures, which are combined with averaging process to smooth out high frequency noise (Roland *et al.* 1993; Worsley *et al.* 1996a). The need for smoothing arising here is closely related to the more general multi-scale nature of real-world data. Objects may appear in different ways depending on the scale of observation, and without information about what scales are appropriate for describing a given data set, the only reasonable approach is to consider a *multi-scale data representation* (Koenderink 1984; Lindeberg 1994).

Indeed the problem of multi-scale extraction of blob-like (*i.e.*, peak-like) structures from image data and selecting scales for these has been extensively studied in the field of computer vision (Lindeberg 1993ab, 1994). In this work, we report the result of using a specific type of image representation referred to as the *scale-space primal sketch* for multi-scale hierarchical clustering of blob-like patterns in brain activation data, *i.e.*, extraction of significant blobs which are likely to correspond to functional areas.

A complete description of the approach cannot be given here, and the reader is referred to (Lindeberg 1993a, 1994; Lidberg *et al.* 1997) for details. In summary, the method consists of smoothing the 3-D image data by convolution with Gaussian kernels of different width, and defining a hierarchical tree-like structure of nested extremum regions at each scale is defined from a watershed analogy such that each leaf in the tree corresponds to a local maximum. Such an object is referred to as a *grey-level blob*, and the entire tree structure as the grey-level blob tree. In general, for a grey-level blob there will be a similar blob at a slightly coarser and a slightly finer scale, and topologically similar blobs at adjacent scales are linked across scales to objects called *scale-space blobs*. Bifurcations between blobs are registered and these delimit the extent of the scale-space blobs in the scale direction. The bifurcations also give rise to hierarchical relations between blob regions at different scales.

For each scale-space blob, its (five-dimensional) scale-space blob volume is computed (three spatial dimensions, one intensity dimension and one scale dimension), and these scale-space blob volumes are normalized with respect to the statistics of noise patterns. The scale-space blobs are ranked on significance in decreasing magnitude of scale-space blob volumes, and for each scale-space blob the scale is selected for which the normalized grey-level blob volume assumes its maximum value over scales.

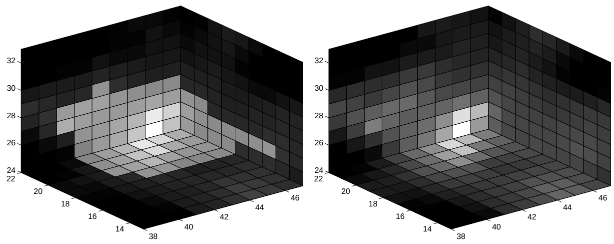

Figure 1: Example of a significant scale-space blob (left) as extracted automatically from a brain activation pattern (right).

There are similarities between this approach and the work by (Poline and Mazoyer 1994) who define a structure essentially corresponding to the grey-level blob tree (Lindeberg 1993a) at each scale, and (Worsley *et al.* 1996b) who select scale levels from local maxima with respect to scale and space (Lindeberg 1993b, 1994). The fundamental difference is that we simultaneously (and adaptively) select scale levels, delimit spatial support regions and rank structures on their stability over scales in scale-space.

To conclude, we propose that the scale-space primal sketch concept is ideally suited as a tool for analysing brain activation patterns, since (a) it automatically extracts regions of interest from image data and delimits their extent relative to adjacent (competing) patterns, and (b) it automatically adapts its scale levels to the data, thereby eliminating the need for manual tuning of the smoothing parameter prevalent in previous multi-scale approaches.

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