Blurring fMRI Data to a Specified Smoothness: in 2D, in 3D, and on Surface Models

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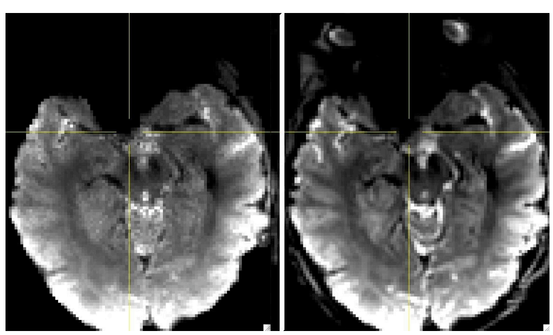
Introduction: Controlling the smoothness of echo-planar images is an important factor in multi-site FMRI studies [1]. FMRI datasets are commonly smoothed spatially, both to reduce the noise and to control multiple comparisons. An image is easily smoothed by convolving it with a Gaussian kernel. However, at the edges of the brain, this procedure will blur brain voxels together with noise-only voxels. Smoothing should not mix data and non-data together. We present here a method for blurring images to a desired level of smoothness (which includes any intrinsic smoothness from data acquisition and reconstruction), which also preserves the brain/non-brain boundary.

Method: Convolution of image $I(\mathbf{x})$ with a Gaussian kernel is equivalent to solving the diffusion equation $u_t=D\nabla^2 u$ forward in time, with initial condition $u(\mathbf{x},t=0)=I(\mathbf{x})$, and with no boundary conditions. Blurring with a boundary (*i.e.*, within a brain mask) can similarly be conceived as solving the diffusion equation forward in time with Neumann (reflecting) boundary conditions at the edge of the mask. A simple method for approximating the solution to this PDE problem is to use a conservative finite difference scheme with Euler time stepping on the general diffusion equation $u_t=\nabla\cdot[\mathbf{D}(\mathbf{x},t)\nabla u(\mathbf{x},t)]$. Nothing "leaks" into or out of the mask by construction of the difference method.

Image smoothness may need to be adjusted locally, which is why the diffusion tensor $\mathbf{D}(\mathbf{x},t)$ is allowed to vary. In the neighborhood of each voxel, the local smoothness can be estimated using the local variance of the first differences [2]. If the smoothness at a location $\mathbf{x}$ is close to the target smoothness, then $\mathbf{D}(\mathbf{x},t)$ can be set to zero there.

The method outlined above is incorporated into the AFNI software package. Images in a time series are incrementally smoothed (in 2D or 3D) until a global smoothness criterion (FWHM=**F**ull **W**idth at **H**alf **M**aximum) is met. Regions where the local smoothness reaches the criterion early are not over-smoothed – this feature may be especially useful when used with SENSE imaging methods, where the noise statistics can vary spatially. Using this program, multi-site FMRI studies can be easily be analyzed with images from all sites converted to a common level of smoothness.



2D-Blur to FWHM=7 mm   Original EPI Data

{8 Channel SENSE Acquisition at 3 Tesla}

This algorithm has also been adapted to smoothing datasets defined over triangulated models of the cortical surface [3]. Smoothing is again estimated and controlled locally (appropriately modifying the likelihood-based FWHM estimation to allow for irregular inter-node distances), and blurring is done using a local approach. Using the AFNI+SUMA software package, EPI datasets can be projected to a surface model, then smoothed to a given level, then the usual GLM-type analysis applied to these surface-based time series to produce activation maps directly on cortical surface models.

References:

[1] Friedman L, Glover GH, Krenz D, Magnotta V. *Neuroimage* **32**:1656-1668 (2006).

[2] Forman SD, Cohen JD, Fitzgerald M, Eddy WF, Mintun MA, Noll DC. *Magnetic Resonance in Medicine* **33**:636-647 (1995).

[3] Hagler DJ, Saygin AP, Sereno MI. *NeuroImage* **33**:1093-1103 (2006).

Category: *Modeling and Analysis*
Sub-Category: *Exploratory methods, artifact removal*