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Project A3: Image processing and signal detection in medicine and biosciences

Structure adaptive smoothing medical images

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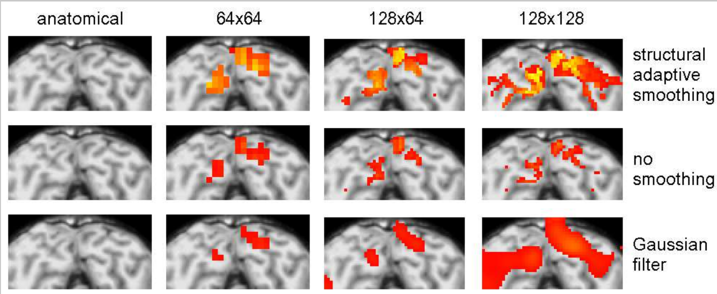
Medical imaging

Medical imaging includes a variety of techniques, like X-Ray, CT, and MRT. A high noise level and very low signal-to-noise ratio together with heteroskedastic tissue dependent variance is often a serious problem. Objects and signals of interest are very weak and can hardly be detected. Methods and algorithms to handle this kind of data should be able to reduce noise while preserving important structure like edges and homogeneous regions.

Structure adaptive smoothing removes the noise without loosing the structural information. This leads to substantial improvements in the analysis of various types of medical images.

Functional Magnetic Resonance imaging (fMRI)

Data from functional MRI consists of time series of brain images which are characterized by a high noise level and a low signal-to-noise ratio. In order to reduce the noise, improve signal detection and to weaken the multiple test problem fMRI data is spatially smoothed. We developed a **structure adaptive smoothing** procedure that significantly improves the information on the spatial extent and shape of the activation regions compared with common non-adaptive filtering.



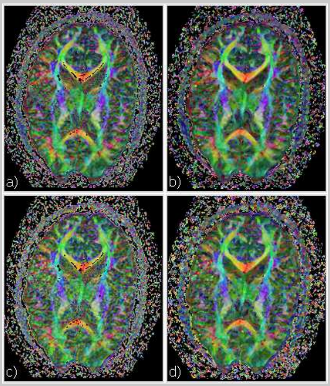
Signal detection for an experiment with visual stimulus (flashing checkerboard) at different resolutions and with different smoothing methods. The columns from left to right correspond to an anatomical view without functional overlay for comparison, a $64x64$, $128x64$, and $128x128$ matrix size. The upper row is the result after structure adaptive smoothing, the middle row without any smoothing, the lower row with Gaussian filtering with comparable bandwidth.

Resolution vs. SNR

The signal-to-noise ratio (SNR) decreases with increasing spatial resolution. Therefore, weak signals can hardly be detected without noise reduction at higher resolution. However, non-adaptive smoothing like Gaussian filtering inherently lowers the effective resolution. Thus, it is not possible to utilize the advantages of the higher resolution.

In contrast to this, we can show, that with **structure adaptive smoothing** we are able to improve signal detection at acquisition resolution. This can be seen in the left figure where the activation areas match the grey matter much better at the highest resolution. Note, that the anatomical information has *not* been used in the smoothing procedure!

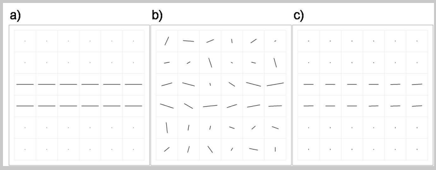
DTI Experiment



Reconstruction of the diffusion data using 55 (a,b) and 30 field gradients (c,d) without smoothing (a,c) and with **structure adaptive smoothing** (b,d).

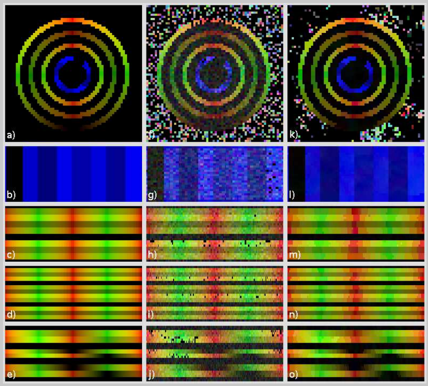
Diffusion Tensor Imaging (DTI)

Diffusion Tensor Imaging suffers from significant noise, which effects subsequent medical analysis with fiber tracking or anisotropy maps. However, noise reduction with commonly applied non-adaptive smoothing methods tend to oversmooth fine anisotropic structures of interest. Using a **structure adaptive smoothing** method that identifies and uses anisotropy information in the data is therefore essential, to improve subsequent medical analysis like fibre tracking or anisotropy maps.



Vector field of main diffusion direction in simulation data (a), disturbed by noise (b), after **structure adaptive smoothing** (c).

DTI Simulation



Reconstruction of a numerical phantom mimicing features of experimental DTI data. Directionally encoded color FA maps obtained from the phantom (a)-(e), voxelwise reconstructions from noisy data (h-j), and **smoothed** results (k-o).

Software

Many of our methods are available as software packages for the R Language for Statistical Computing or are adapted to environments like AMIRA^{TM} or Matlab.

- R-packages: *fmri*, *dti*
- toolbox *aws4SPM* for SPM
- *aws4AMIRA*

References

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- K. Tabelow, J. Polzehl, A. M. Ulug, J. P. Dyke, R. Watts, L. A. Heier, and H. U. Voss. *Accurate Localization of Brain Activity in Presurgical fMRI by Structure Adaptive Smoohting*, IEEE Trans. Med. Imaging **27(4)**, 531-537 (2008).

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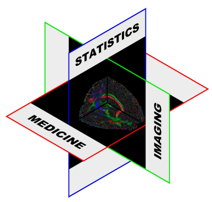

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