

## Novel algorithms to measure complexity in the human brain and to detect statistically significant complexity-differences

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## 1. Purpose

To measure brain-complexity in segmented MR-images global measures of the fractal dimension (FD), like the density-density correlation or the box-counting method (BCM) are frequently used, where a regression line must be estimated from the data <sup>1</sup>. It was shown by Sandau <sup>2</sup> that FDs based on regression methods are sensitive to rotations and to noise. In addition, the basic maximum property of FDs is violated,  $FD(\text{Set}_1 \cup \text{Set}_2) = \max\{FD(\text{Set}_1), FD(\text{Set}_2)\}$ . Therefore, we implemented a more local algorithm reducing the erroneous impact of distortions which is closer to the mathematical concept of a FD <sup>2</sup>. As second, an advanced statistical method <sup>3</sup> with high power was implemented to test differences of FDs.

## 2. Methods and Materials

The proposed algorithm for calculation of FD proceeds for fractal data on a grid of voxels in  $R^3$  shortly like follows. 1) Define  $p_1$  and  $p_2$ ;  $p_1 = -\ln(\text{voxelsize})$ ,  $p_2 = -\ln(\text{windowsize})$  for a large observation window. 2) Shift the window within the grid and count for every window position  $j$  the number  $N_j$  of voxels containing the fractal object. 3) FD is estimated by  $x_{dim} = \max_j \{ \ln(N_j) / (p_1 - p_2) \}$ .

[see: \[fig1.jpg\]](#)

To detect significant differences of FDs a Monte Carlo procedure was implemented using permutation resampling. Raw and multiplicity adjusted P-values are calculated. This non parametric statistical step-down-method <sup>3</sup> strongly controls the family-wise error, includes all logical restrictions and includes the correlations between the P-values.

## 3. Results

To demonstrate the advantage of  $x_{dim}$  compared to BCM-dim, a plane with blood vessels was analyzed.

[see: \[fig2.jpg\]](#)

In Fig.2 the dimensions for the original, framed, rotated and weakly disturbed data are presented. Evidently,  $x_{dim}$  is more robust. An attempt to analyse lobes of a single human cortex malformed by disease is presented in.

[see: \[fig3.jpg\]](#) [see: \[fig4.jpg\]](#)

The cortex was segmented from T1-weighted MR data <sup>1</sup>. The cortex surface between gray and white matter was then extracted by morphological dilation. To produce simple 'lobes', the resulting fractal object was divided into quarters by a central axial and sagittal slice.  $x_{dim}$  was finally calculated for these quarters (2.467, 2.479, 2.418, 2.405) and for four (up-down/left-right) halves (2.479, 2.418, 2.467, 2.479). The raw and adjusted P-values for 8 pairwise FD-differences are shown in Fig. 3. In Fig. 4 for the same 'lobes' the differences of the mean surface densities ( $\text{mean}_j \{ \ln(N_j) / (p_1 - p_2) \}$ ) are compared.

## 4. Conclusion

Advantages of  $x_{dim}$  are exemplified. A preliminary cortex analysis indicates that the detection of statistically significant FD-differences and of mean surface-densities between individual lobes may be feasible. Critical for resampling tests is the correlation within the samples  $\{N_j\}$ . This effect is 'minimized' by an alternative sampling of local  $x_{dim}$ 's for disjoint boxes covering a fractal (see fig1.jpg). A spatial autocorrelation analysis to quantify remaining statistical dependences is in progress.

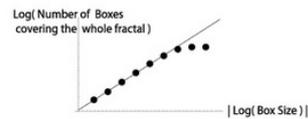
## 5. References

- <sup>1</sup> Kiselev, V.G., Hahn, K.R., Auer, D.P., 2003, NeuroImage, 20, 1765-1774. <sup>2</sup> Sandau, K., 1996, Physica A, 1-18.  
<sup>3</sup> Westfall, P.H., 1997, AmStatAss, 51/1, 3-8.

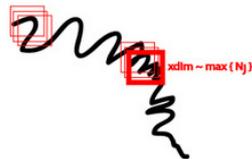
## 6. Mediafiles:

fig1.jpg

bcm Definition :



xdim Definition :



note : xdim is more local than the box counting dimension

xdim Approximation :



disjoint box-contents  $N_j$  are weakly (or not) dependent, these  $N_j$  may be useful for resampling tests

fig2.jpg

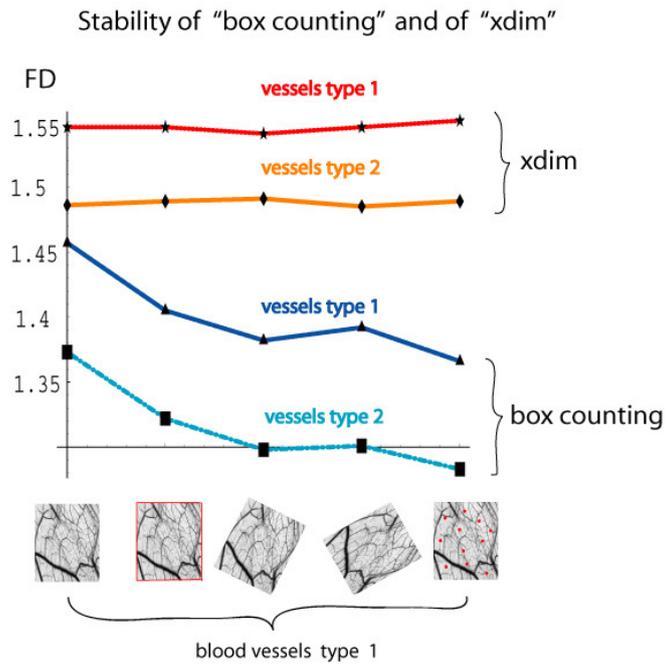
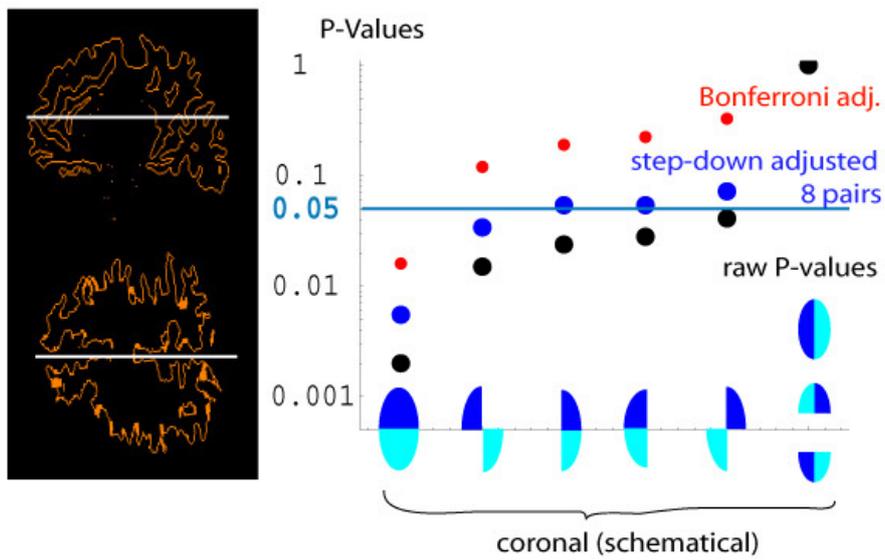


fig3.jpg

### Significant differences of xdim between "Lobes" of an individual Cortex



### Significant differences of the mean complexity between "Lobes" of an individual Cortex

