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Evaluation of bootstrap procedures for fMRI data

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Problem

- Bootstrap procedures for fMRI time series have become popular: e.g. thresholding, ...
- Friman and Westin (2005)[1]: in *blocked* designs GLM-based **pre-whitening** better than Fourier or Wavelet decomposition
- fMRI data is both spatially and temporally complex
- **whitening**: **parametric** noise model ↔ **blocked**: **model-free** noise model [2]
- Smoothing heavily affects the data: should it occur before or after bootstrapping?

Goals

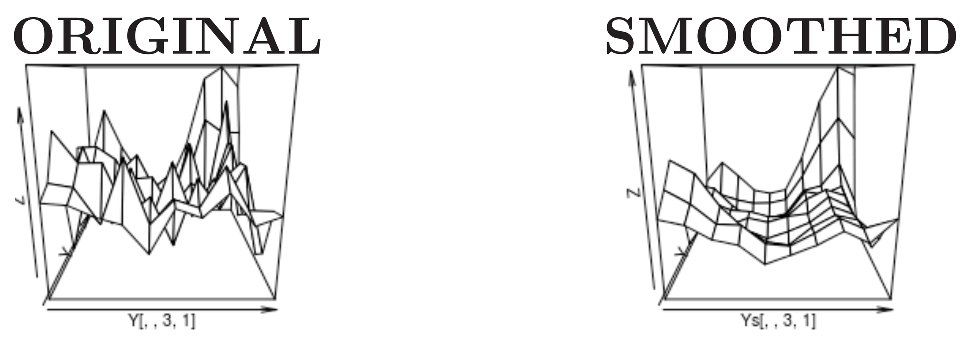
- Account for data complexity while bootstrapping
- Focus on spatial and temporal **reconstructability** of the original volume
- **Comparison** of blocked bootstrap (BR), pre-whitening bootstrap(W) and combination of both[3] (BW) as bootstrap procedures for the resampling of **GLM-residuals**

Resampling GLM-residuals

- fMRI data analysed typically using $Y_{it} = X_{it}\beta + \epsilon_{it}$ with $\epsilon_i \sim N(0, \mathbf{V}\sigma^2)$ for each voxel i and time point t
- In SPM8: $\mathbf{WVW'} = \mathbf{I}$ with W is estimated as *quasi* $AR(1)$ structure
- $\boldsymbol{e_{white}} = \boldsymbol{W e_{raw}} = \boldsymbol{W y_i} - \boldsymbol{W x_i}\hat{\boldsymbol{\beta}}$ assumed to be uncorrelated BUT $E(\boldsymbol{e_{white}}) \neq 0$
- *Whitening* bootstrap uses e_{white} and *blocked* bootstrap uses e_{raw}
- we use **centered studentized**[3] residuals for e_{white} and for e_{raw}: scaled by $\left(\sqrt{1-h_{ii}}\right)^{-1}$: h_{ii} diagonal element of $WX(WX^TWX)^{-1}WX^T$
- 3 scenarios: Independent resampling $\boldsymbol{e_{white}}$ (IW), blocked resampling $\boldsymbol{e_{raw}}$ (BR) and blocked resampling $\boldsymbol{e_{white}}$ (BW) with spatial composition retained over bootstrap sequence by individual resampling over all voxels

Smoothing

- Typical isotropic Gaussian 6mm kernel
- Impact on signal *itself* and noise model
- 3 scenarios: (B) Before bootstrap, (A) after bootstrap or (BA) both ?

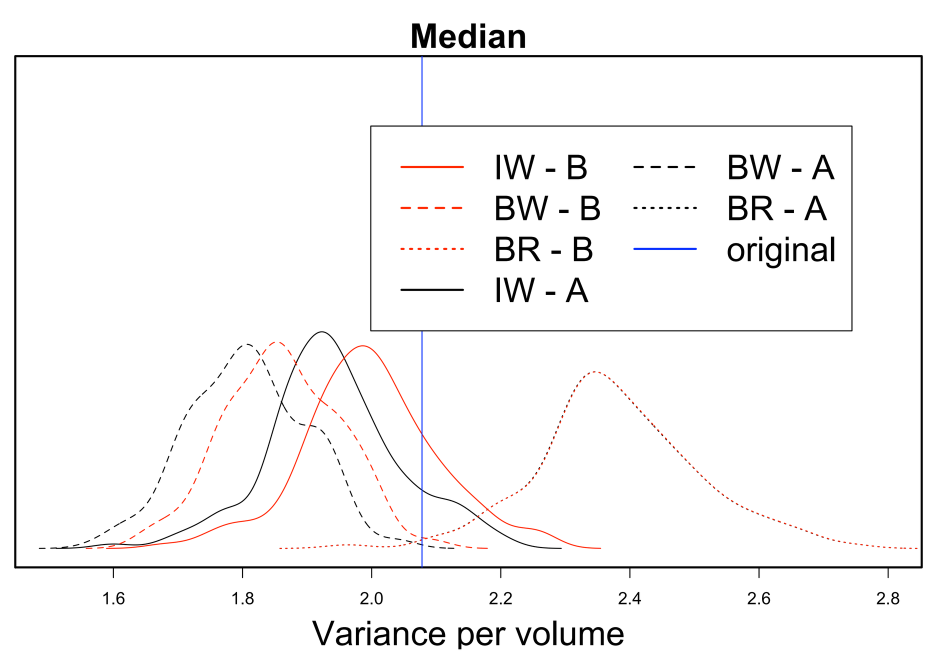


Exploration on the SPM `auditory` dataset[4]

- Comparison of spatial and temporal properties of the 150 bootstrap samples versus properties of the original data
- We evaluate raw residuals :$\boldsymbol{e_{raw}} = \boldsymbol{K y_i} - \boldsymbol{K x_i}\hat{\boldsymbol{\beta}}$, with $\boldsymbol{K}$= standard 128 s cut-off high-pass filter to compare the bootstrapped volumes with the original volume
- For both BW and BR bootstrap scheme blocks of 7 observation were used ("optimal" block length)

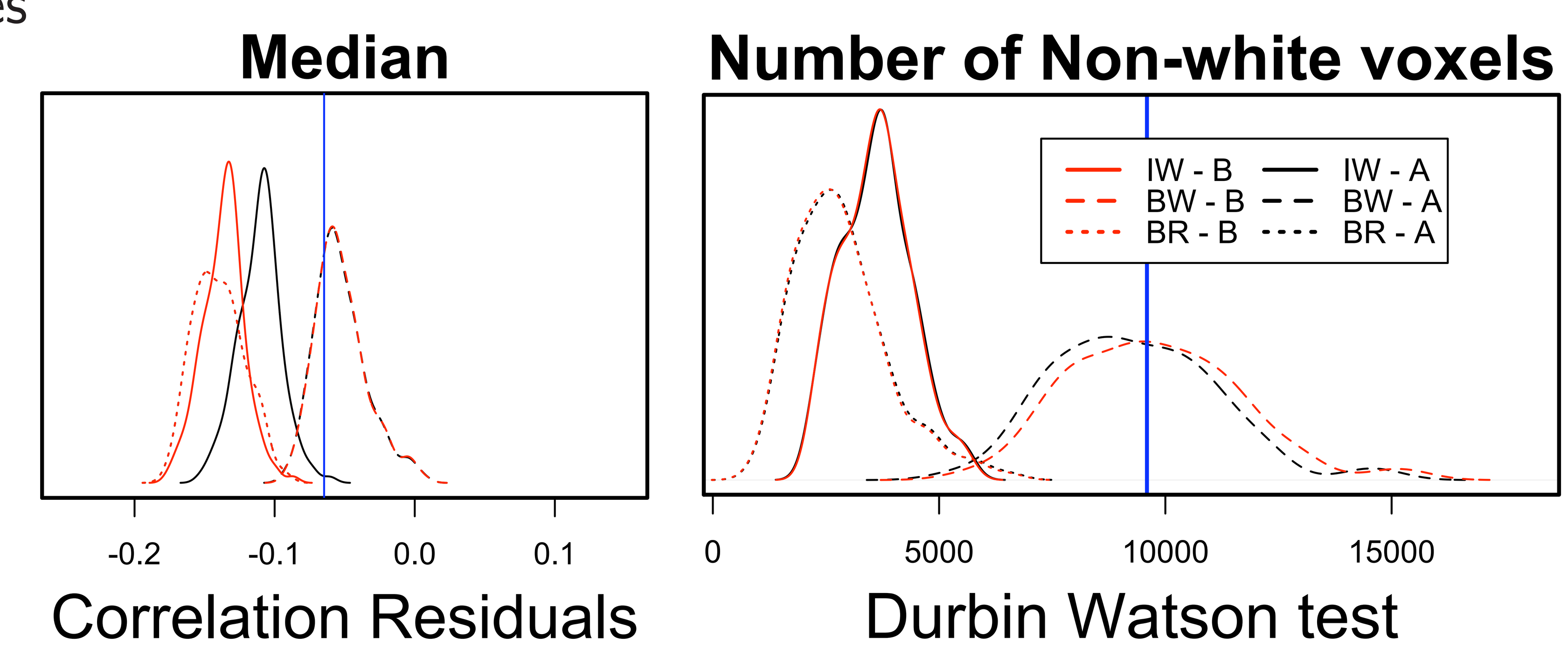
Spatial reconstructability

- BA smoothing, bootstrap samples are too smooth (up to twice as smooth) Smoothness is preserved well in both B and A
- Spatial variability has no clear pattern



Temporal reconstructability

- Result of BA smoothing are omitted due to too little variation
- Durbin Watson test statistic is based on the whitened residuals of the bootstrapped volumes



- The BR bootstrap induced a higher degree of variability in the raw residuals compared to the other bootstrap schemes

Conclusions

- **Smoothing locus** Small differences B or A, but BA is too smooth
- **Bootstrap scheme** BW preserves the temporal correlation in the residuals
- Spatial variability needs further exploration
- **Confirmation needed** from other datasets and from simulation studies

Remarks

- `Auditory` dataset is an old dataset with long TR
- Limited amount of smoothing (6 mm)
- No impact of block length investigated yet

References

[1] Friman, O, & Westin, C-F (2005). *Resampling fMRI time serie*, NeuroImage, 25, 859-867.

[2] Lahiri, S.N. (2003). *Resampling methods for dependent data*, Springer.

[3] Davison, A.C & Hinkley, D.V. (1997). *Bootstrap Methods and their Applications*, Cambridge University Press.

[4] Friston, Karl et al. (2007). *Statistical Parametric Mapping: The Analysis of Functional Brain Images*, Elsevier Ltd./Academic Press