# When temporal similarity is mistaken for representational similarity: a Bayesian approach to reduce bias in RSA of fMRI data

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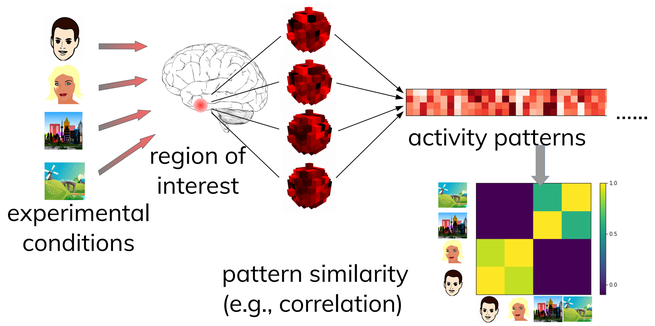
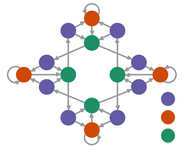
## Representational similarity analysis (RSA)[1,2]:

finding the brain's representational structure from neural imaging data

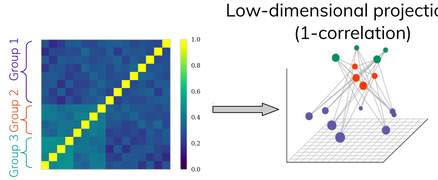



## Bias in standard RSA

An example decision making task: transitions between task states follow a Markov process[3]

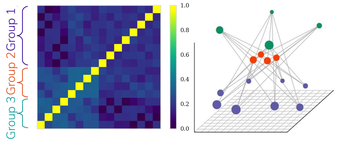



Representational similarity structure in one brain area appears to reflect the task structure

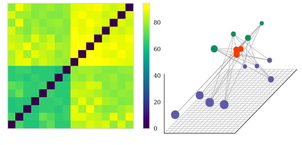



But similar structure is also found when applying RSA to white noise

Similarity measured by Pearson correlation




Dissimilarity measured by Euclidean distance



Task-related structure should not exist in white noise. There must be a bias.

## BrainIAK

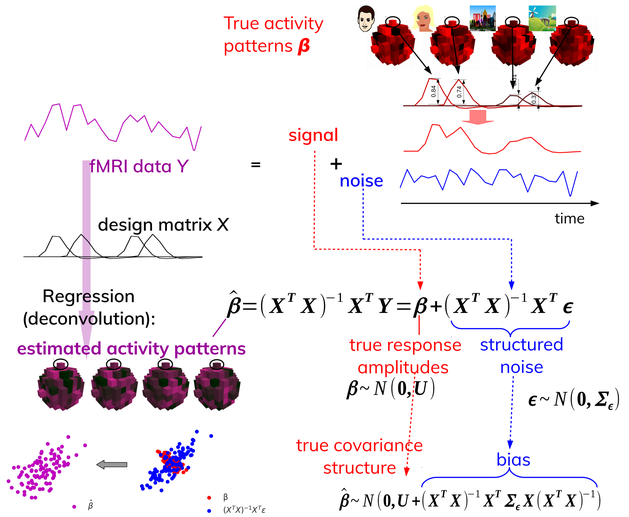
Bayesian RSA is available in the BrainIAK python package for high-performance neuroimaging analysis.
For additional information on BrainIAK, see brainiak.org/sfn2017

## Reference

[1] Kriegeskorte et al., (2008) Representational similarity analysis - connecting the branches of system neuroscience. Frontiers in Systems Neuroscience
[2] Haxby, et al., (2001) Distributed and overlapping representations of faces and objects in ventral temporal cortex. Science
[3] Schuck et al., (2016) Human orbitofrontal cortex represents a cognitive map of state space. Neuron
[4] Cai, et al. (2016) A Bayesian method for reducing bias in neural representational similarity analysis. NIPS
[5] Alink et al., (2015) Mind the drift – Improving sensitivity to fMRI pattern information by accounting for temporal pattern drift. BioRxiv
[6] Heriksson et al. (2015) Visual representations are dominated by intrinsic fluctuations correlated between areas. NeuroImage
[7] Diedrichsen et al., (2016) On the distribution of cross-validated Mahalanobis distance. arXiv

## Source of the bias

Recall: general linear model

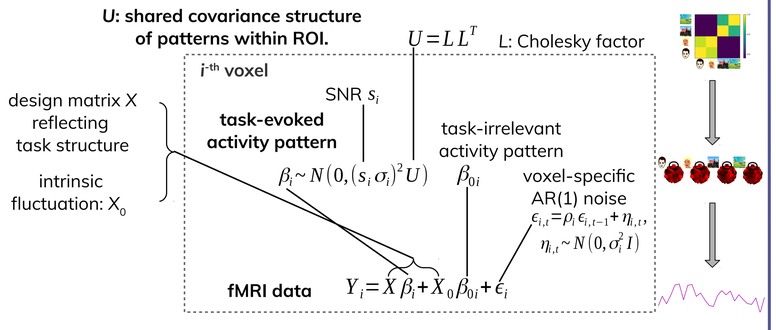



Structured noise in the estimated activity patterns turns into bias in their covariance structure.
The bias structure depends on the structure of the task and the property of the noise.

## Bayesian RSA[4]

**Goal**: to estimate covariance structure of activity patterns directly from data, without using point estimates of patterns.

### Generative model




Marginalizing all intermediate variables results in likelihood function directly linking covariance structure ***U(L)*** and fMRI data Y.

*i*-th voxel: $p(Y_i|U(L),\sigma_i,\rho_i,s_i)=\int\int p(Y_i|\sigma_i,\rho_i,\beta_i,\beta_{0i})\,p(\beta_i|L,s_i\sigma_i)\,d\beta_{0i}\,d\beta_i$

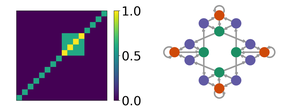
all data: $\log p(\boldsymbol{Y}|U(L))=\sum_i \log\int\int\int p(Y_i|U(L),\sigma_i,\rho_i,s_i)\cdot p(\sigma_i,\rho_i,s_i)\,ds_i\,d\rho_i\,d\sigma_i$

### Parameter estimation

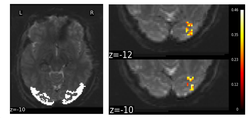
*Maximum likelihood estimation* of L is obtained by gradient-based methods.
$X_0$ is estimated from residual noise during iterative fitting

$\hat{U}=\hat{L}\hat{L}^T$ ⟶ Converting to similarity matrix

## Performance

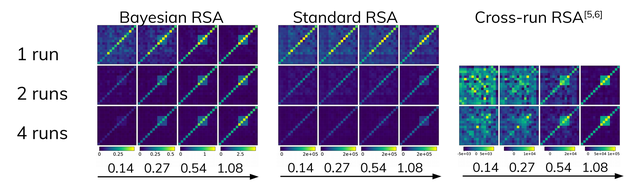


Simulate signals with a hypothetical covariance structure and the design matrix of the 16-state task

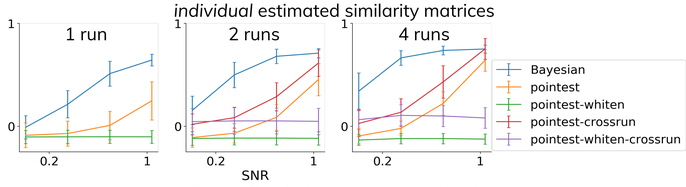


Add simulated signals to a subset of voxels within an area of resting-state fMRI data

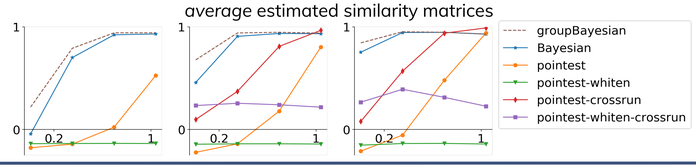
recovered covariance structure




Correlation between simulated and *individual* estimated similarity matrices

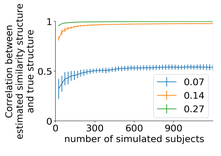



Correlation between simulated and average estimated similarity matrices

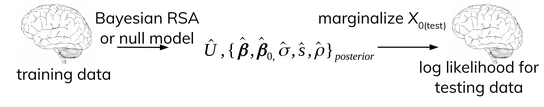



## Model cross-validation

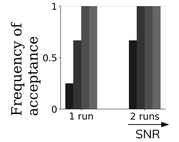
Solution: contrasting a full Bayesian RSA model with its corresponding null model.
Null model: no task-related responses



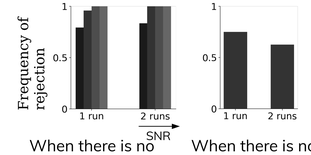

Bayesian RSA is not fully unbiased.




Successfully accepting full model when both data have task-related signals




Full model does not win when data lack task-related signals




When there is no signal in testing data

When there is no signal in either of the data

## Recommendations:

- Avoid using within-run RSA
- Consider Bayesian RSA, cross-run RSA or crossnobis distance[7] as they are less biased
- Try to counter-balance task structure
- Scan more data from each participant when SNR is low