Using realistic, synthetic fMRI data to validate Topological Data Analysis as a tool for fMRI

Cameron Ellis[1,2], Michael Lesnick[1,3], Bryn Keller[4], Chris Baldassano[1], Anna Schapiro[5] & Jonathan D. Cohen[1,6]

1: Princeton Neuroscience Institute; 2: Psychology Department, Yale University; 3: Institute for Advanced Study; Princeton University;
4: Parallel Computing Lab, Intel Corporation; 5: Beth Israel Deaconess Medical Center and Harvard Medical School; 6: Psychology Department, Princeton University

Introduction

fmrisim is a Python library that simulates fMRI data for multivariate and advanced neuroimaging analysis

Topological Data Analysis (TDA) can detect geometric patterns which may describe neural representations

fmrisim

fmrisim can automatically estimate the noise properties of raw fMRI images and generate matched synthetic data

- Load in volume
- Create brain mask
- Estimate noise parameters
- Generate noise volume
- Specify signal
- Combine signal and noise

Automatically estimates:
Brain Mask
Signal to Noise Ratio
Signal to Fluctuation-Noise Ratio
Smoothness
Drift and autoregressive

Can make a signal of any form, e.g. univariate, multivariate

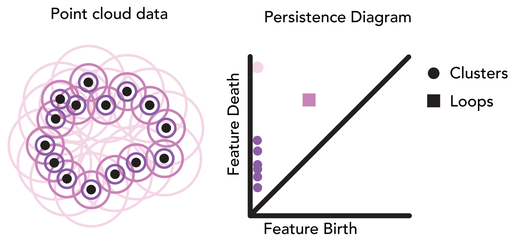
BrainIAK

Analysis performed using the BrainIAK python package for high-performance neuroimaging analysis.
For additional information, see brainiak.org/sfn2017

Topological Data Analysis

Geometric objects are identified by connecting nearest neighbors in the data over different scales

TDA has been useful in medical sciences[1] and holds promise in neuroscience[2] to explore complex high dimensional data

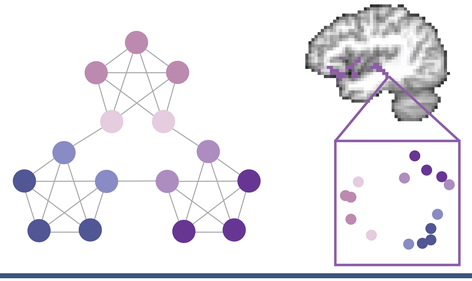


Neural Representations

Neural representations have geometric shapes which may be diagnostic of cognition

Participants are able to extract high level structure from incidental stimulus exposure[3]

The way the brain represents this reflects the topological structure of the input



Discussion

fmrisim can be used to evaluate experimental designs and develop methods

Topolological Data Analysis can extract geometric objects from neural representations

Preserving Topology

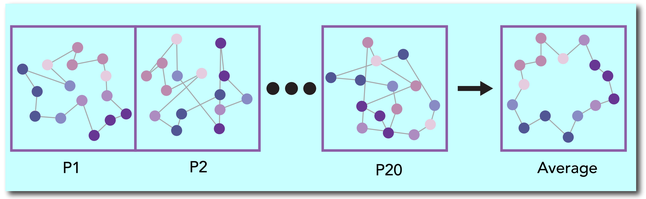
fmrisim was used to generate brains with appropriate noise and community structure

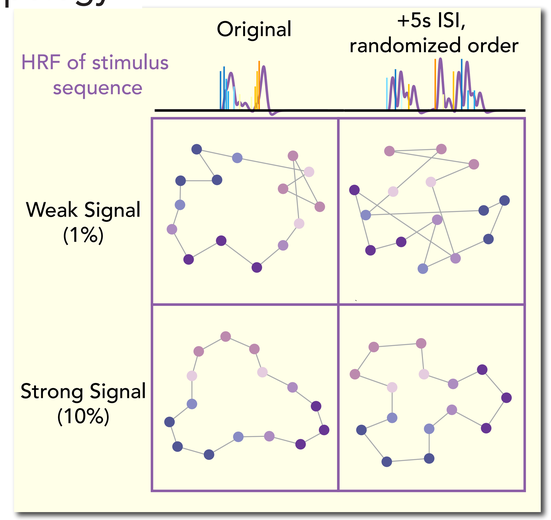
Signal magnitude matched to observed effect size

Design and preprocessing decisions affect topology:

Increase ISI and randomise order

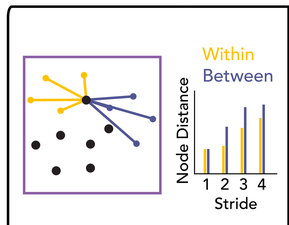
Average across participants

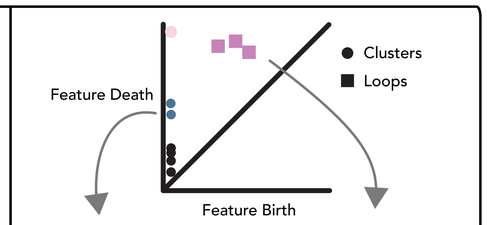




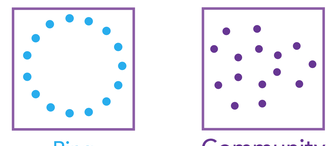
Validating TDA

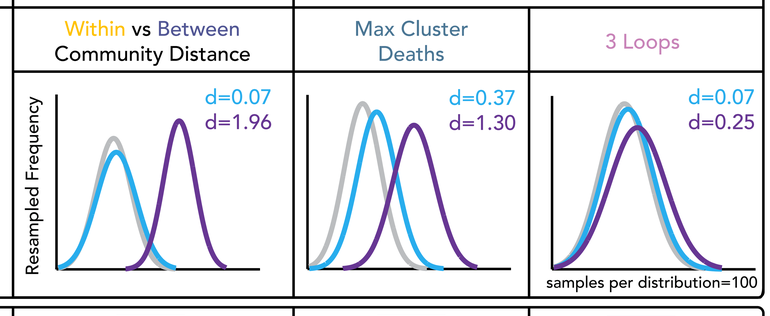
Topological representations can be recovered from task-based fMRI



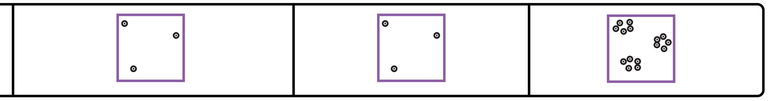


Created brains:
Noise, Noise + Ring signal,
Noise + Community signal





Optimal data for maximizing metric value:



References

1. Nicolau, M., Levine, A. J., & Carlsson, G. (2011). Topology based data analysis identifies a subgroup of breast cancers with a unique mutational profile and excellent survival. Proceedings of the National Academy of Sciences, 108(17), 7265-7270.
2. Karuza, E. A., Thompson-Schill, S. L., & Bassett, D. S. (2016). Local patterns to global architectures: influences of network topology on human learning. Trends in cognitive sciences, 20(8), 629-640.
3. Schapiro, A. C., Rogers, T. T., Cordova, N. I., Turk-Browne, N. B., & Botvinick, M. M. (2013). Neural representations of events arise from temporal community structure. Nature neuroscience, 16(4), 486-492.

Reprints: cameron.ellis@yale.edu