Linear Mapping of Cortio-Cortico Resting-State Functional Connectivity

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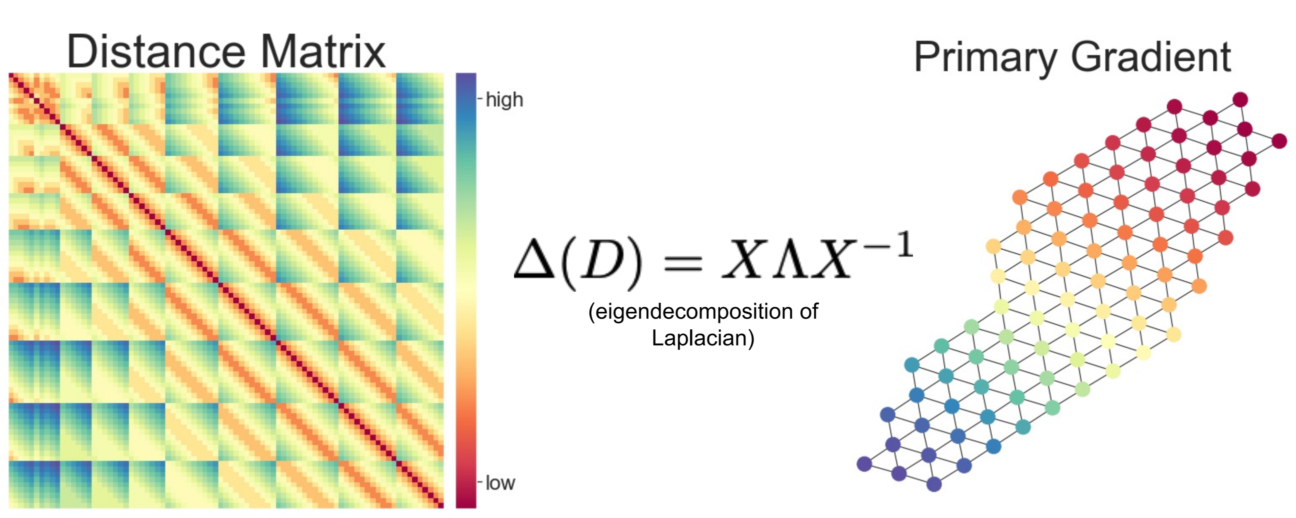
Introduction

Analyzing connectivity between pairs of cortical regions is important for understanding how the brain is structured and how it transmits information. Various cortical areas show graded organization along intrinsic axes defined by functional connectivity [1, 2]. Recent work applies Laplacian eigenmaps to characterize gradients (connectopies) [3] but stops short of relating gradients between region pairs. [4] introduce the idea of pairwise regional linear mapping. Using 150 HCP [5] subjects and corresponding HCP-MMP parcellations, we build off [4] to relate pairwise linear maps to the intrinsic axes defined by functional connectivity.

Methods

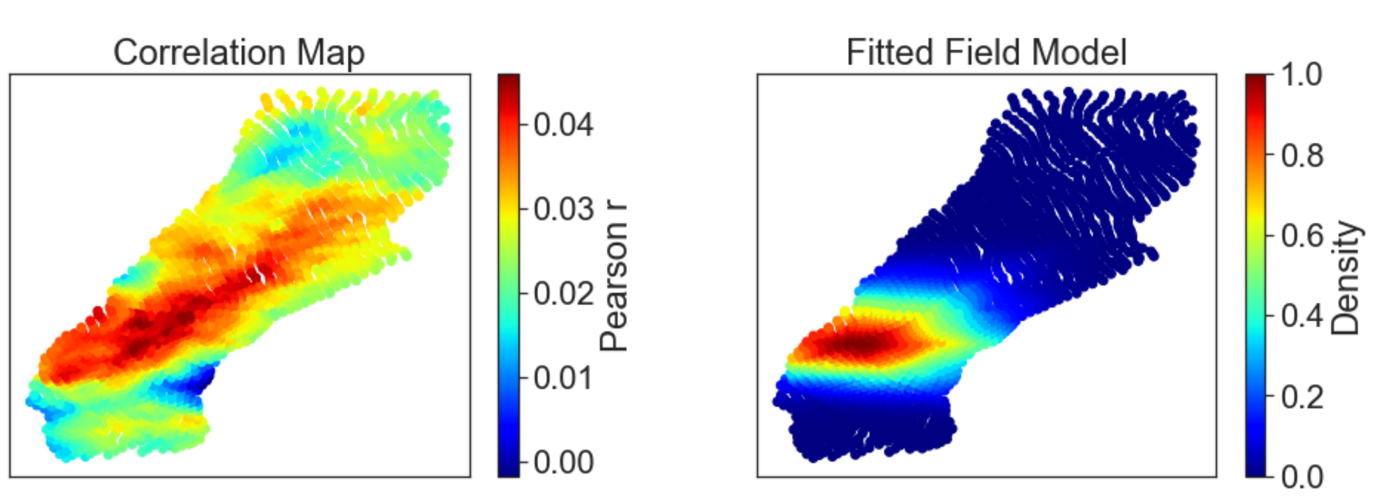
Connectivity Gradients

For each MMP area, we compute the top *K* connectopies as described in [3], describing the intrinsic functional connectivity structure in relation to the rest of the brain. Each vertex in a region is described by its *K*-dimensional embedding vector.



Connective Field Modeling

We consider all heterogenous source-target (*S*, *T*) region pairs. We map each vertex in *S* onto a vertex in *T* by fitting a "connective field model" (CFM) [6] – i.e. we fit a 2D isotropic geodesic Gaussian onto a source vertex's correlation map with *T*. This parameterizes each vertex in *S* with a mean (target vertex) and a variance and generates a general mapping f: *S*→*T* for all (*S*, *T*) pairs.



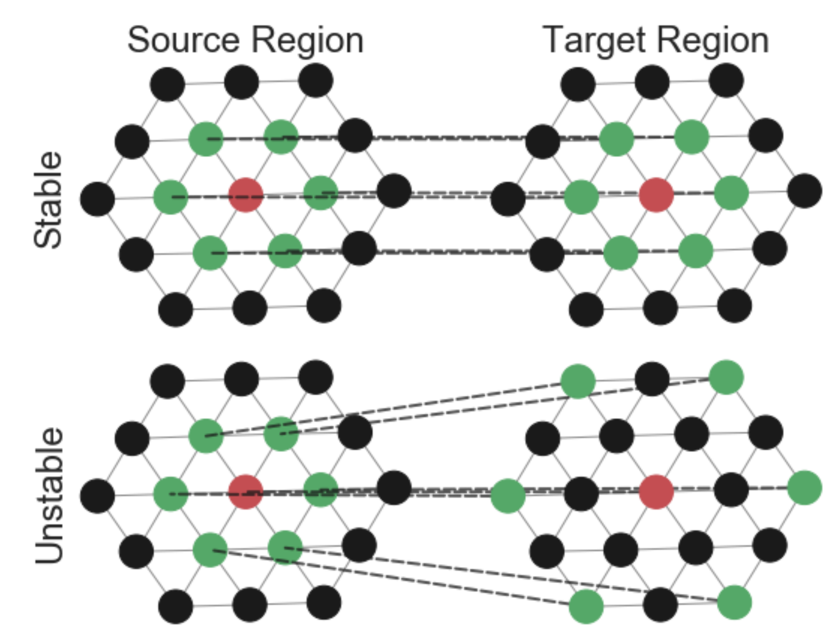
Procrustes Analysis

We treat the *K* connectopies as a coordinate basis. For each (*S*, *T*) pair, we fit the optimal rigid transformation, *A*, of source-to-mapped target coordinates s.t. f(*S*) = *A***S*. We compute a measure of fit (linearity) describing the amount of variation in f(*S*) explained by the mapping for each pair, and aggregate the fits as a square, **asymmetric** matrix.

Methods, cont.

Mapping Divergence

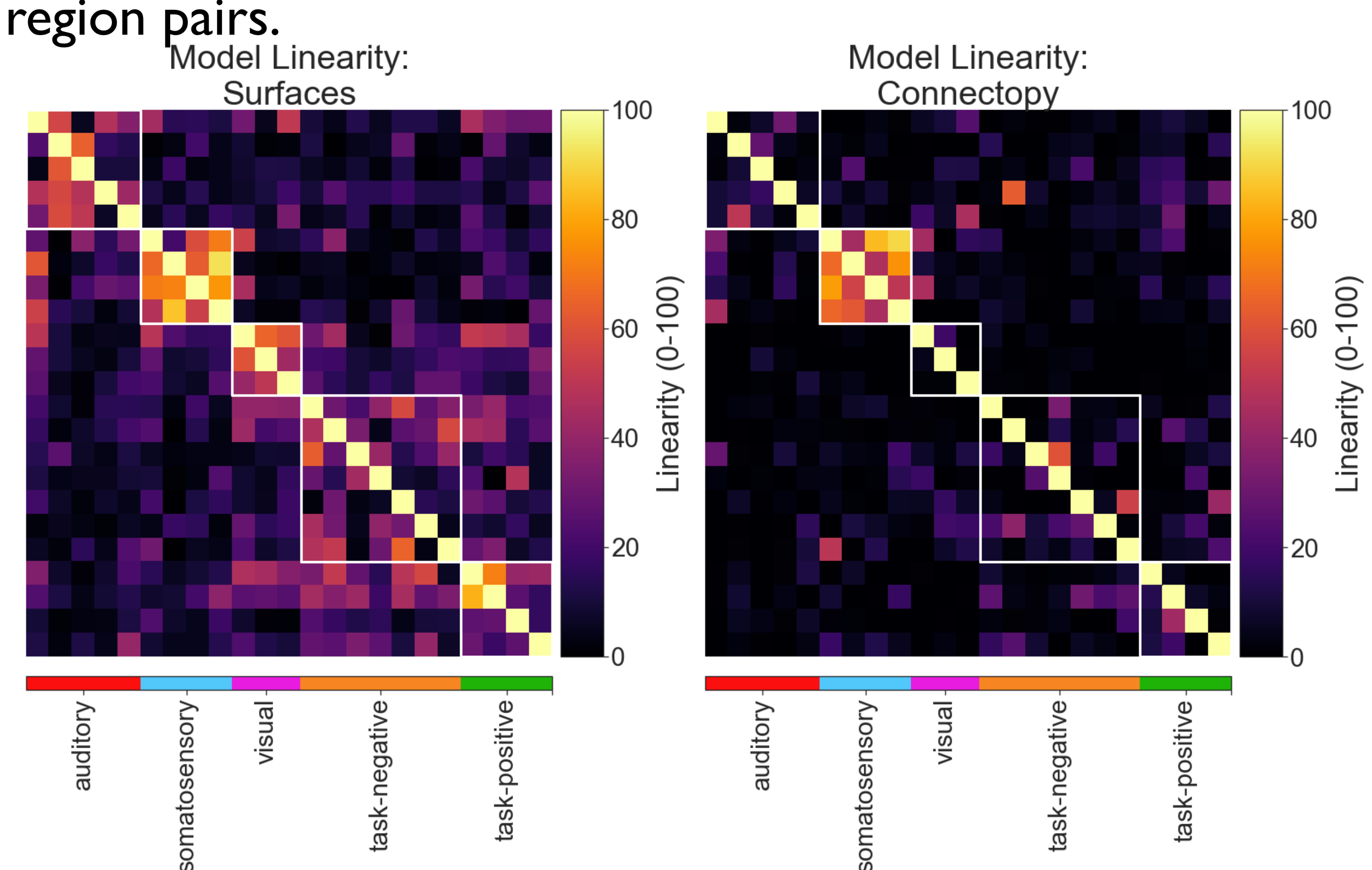
We derive a measure of mapping stability as a property of source regions that we call "divergence": the sensitivity of a mapping to small perturbations in the source vertex location. For a source vertex *s* and its directly-adjacent neighbors s_{adj}, we identify the set of mapped target vertices f({s, s_{adj}}). We compute the pairwise geodesic distance matrix between all pairs in f({s, s_{adj}}) and` take upper diagonal mean of these distances.



Results

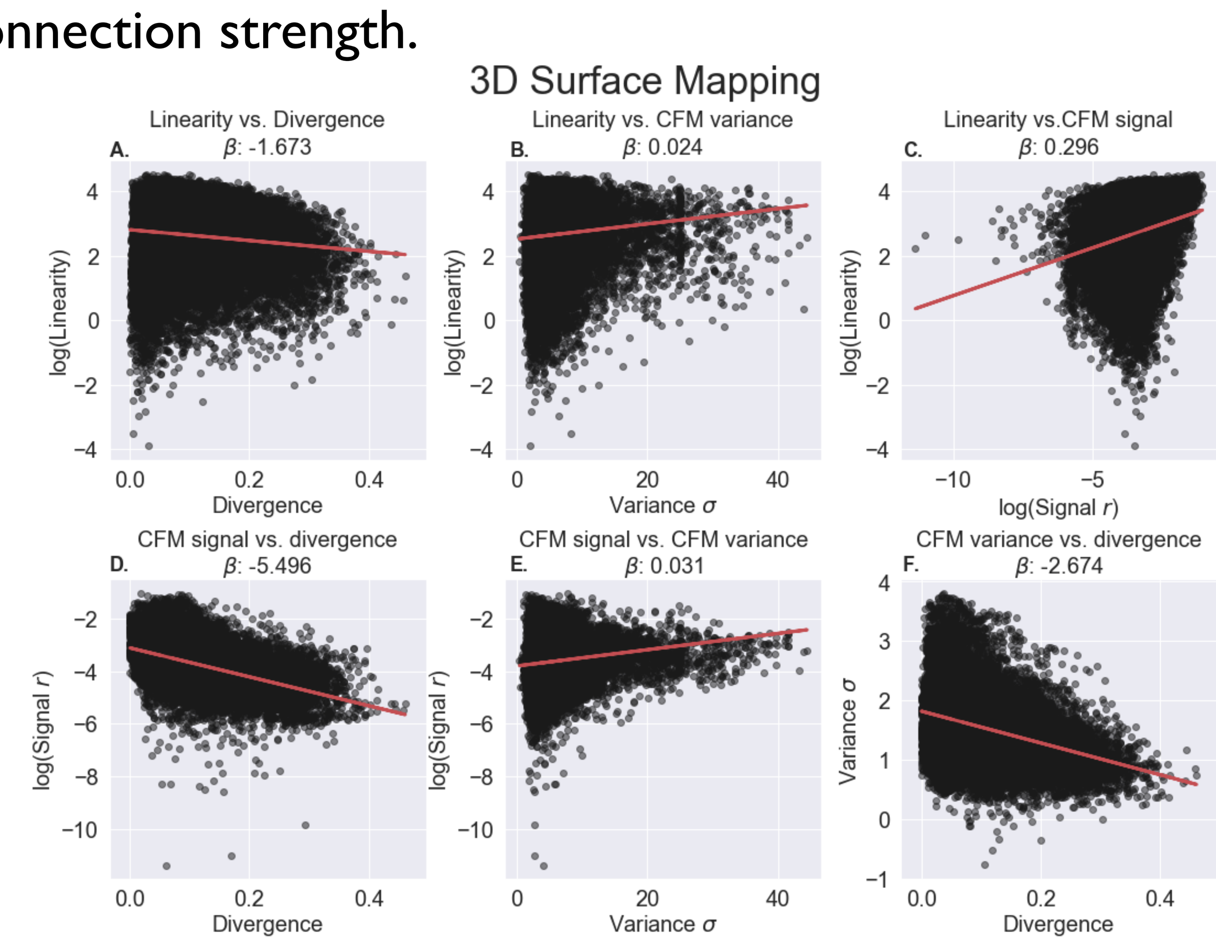
Linearity by Basis Type: 3-D Mesh vs. 2-D Connectopy

We display pairwise mapping linearity values, restricted to regions assigned to unique functional networks (as designated by HCP). We see some evidence of a block-diagonal signal i.e. stronger linearity for within-network region pairs.

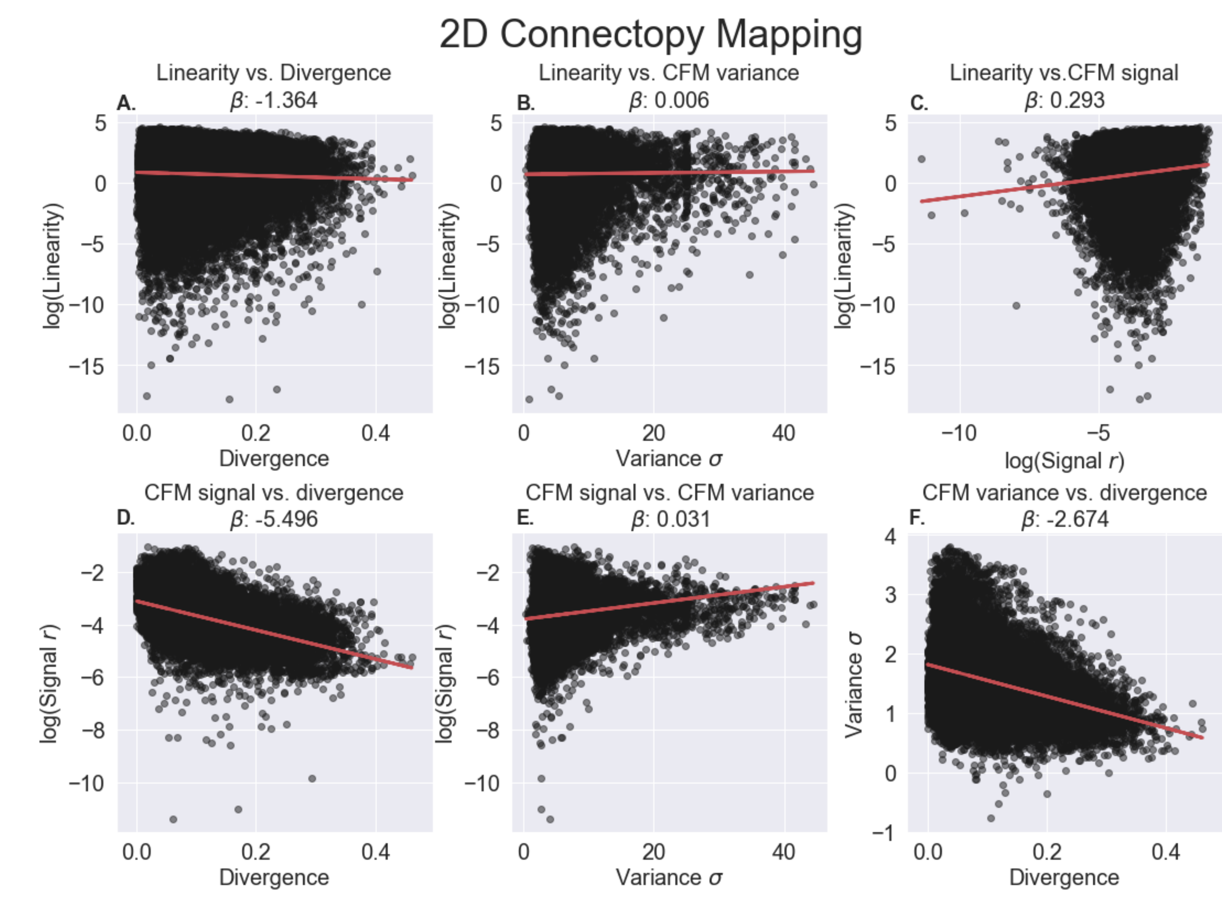


Linearity by Basis Type: 3-D Mesh vs. 2-D Connectopy

We analyze transformation fits as a function of basis type, and compare fitted CFM parameters to divergence and connection strength.



Results, cont.



Conclusions

We hypothesized that:

- extrinsic cortical surface basis would produce lower linearity estimates due to mismatch in folding patterns
- intrinsic functional connectopy basis would yield higher fits (compared to mesh) by better-capturing notions of connectivity directionality

In general, though, we see that the mesh basis yields better fitting models when compared to the connectopies. With regards to the statistical analysis of the mappings, we hypothesized that:

- connection strength and model fit would be positively related
- connection strength and model fit would both negatively relate to model divergence and variance

After log-transforming our variables of interest, we find that model fit is weakly related to variance, negatively related to divergence, and positively related to connectivity signal. Divergence is negatively related to connectivity signal. Our overall conclusions are:

- more strongly connected region pairs show more-structured topographic organization
- less-stable (i.e. more divergent) mappings have a weaker signal and weaker topographic organization

It is likely that choice of cortical atlas impacts measures of topographic organization. We plan to explore pairwise mapping in relation to gradients (in the conventional sense of spatial derivatives) in the connectivity field and explore the idea of connective field mixture models.

References

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