Efficient discovery of functional brain networks in large multi-subject fMRI datasets

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Background & Significance

- Traditional approaches estimate functional connectivity using **pairwise correlations** between voxel time series.

- The **massive computational demands** typically force scientists to focus their analyses on **seed regions** or **regions of interest**.

A daring crew of **explorers**, venturing into the deepest reaches of the **uncharted ocean**, discovers a never-before-seen **treasure trove** of multi-subject fMRI datasets. Can our crew safely extract the precious **brain networks** from the wreckage?

Approach & Model

- The full connectivity matrix is **highly redundant**, since fMRI images contain strong spatial correlations.

- We can leverage this intuition by approximating the full brain network with a simpler K-node network. Each node is a **Gaussian radial basis function** ("sphere").

- We developed **hierarchical topographic factor analysis** (**HTFA**) to determine the optimal node locations, sizes, and per-image weights.

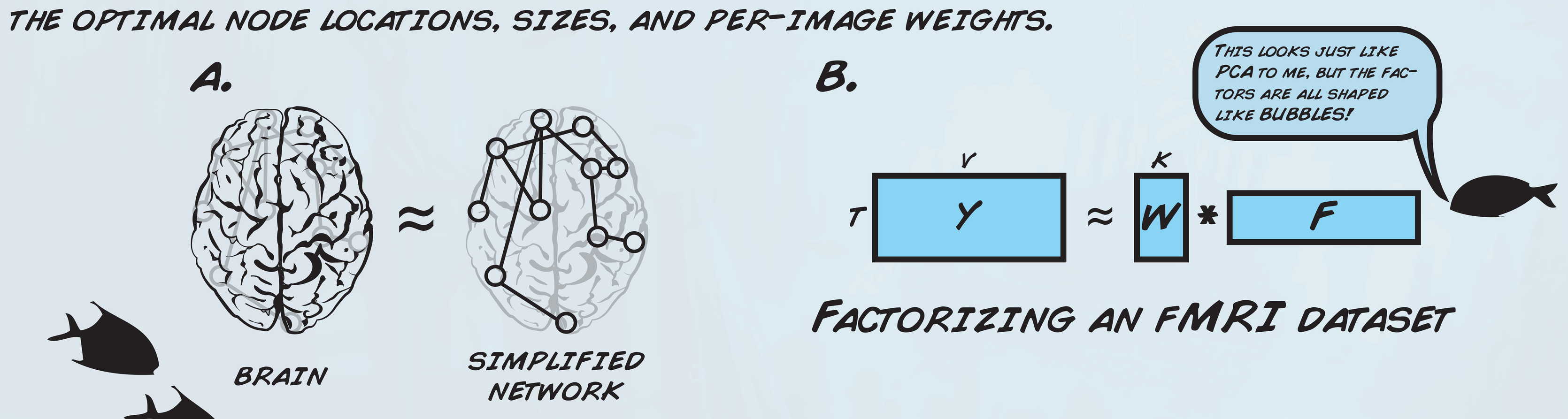


Figure 1. A. K-node network approximation. B. Factor analysis model.

- We use powerful **Bayesian inference** algorithms to efficiently optimize the model parameters.

- We use cross validation to optimize the number of nodes.

- We extend the model to multi-subject data by modeling each **subject-specific model** as a perturbation of a **global template**.

- Our algorithms easily scale to **enormous** datasets with **hundreds** of **thousands** of images.

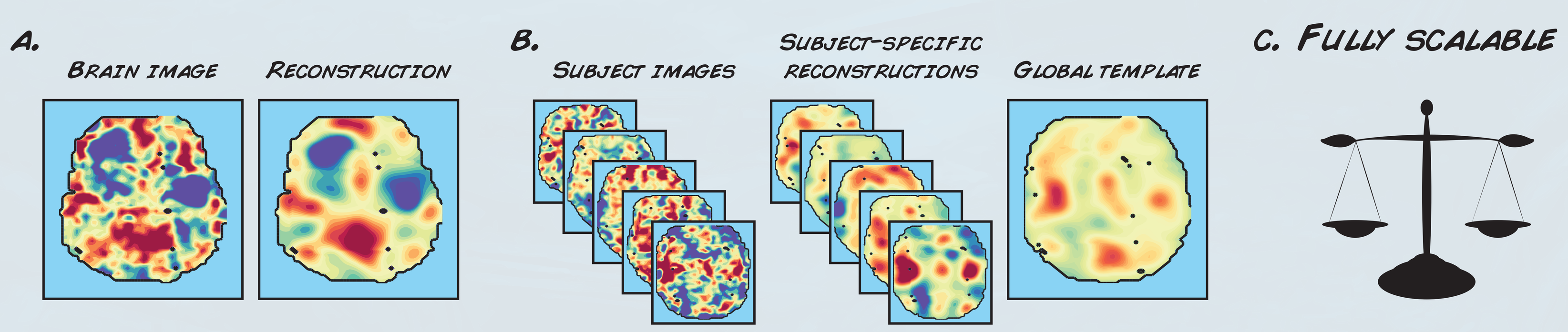


Figure 2. A. Single-subject model. B. Global template. C. A scale.

It soon becomes clear that the **vast amount of valuable data** will be far too **computationally burdensome** to have any hope of bringing this priceless find to the surface. Undaunted, the crew begins to devise an **approximation**...

Results: Simulated Data

- We constructed a **synthetic dataset** whose underlying parameters and connectivity patterns were known, and tested our ability to recover those parameters and connectivity patterns using **HTFA**.

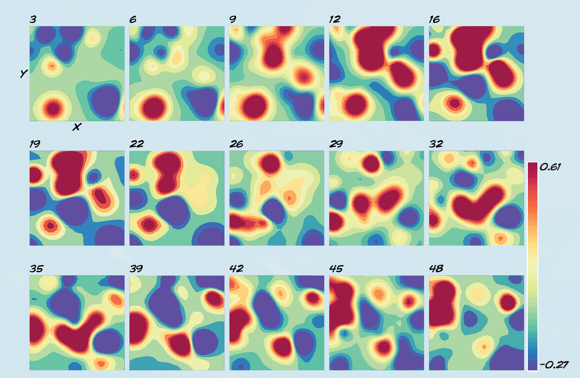
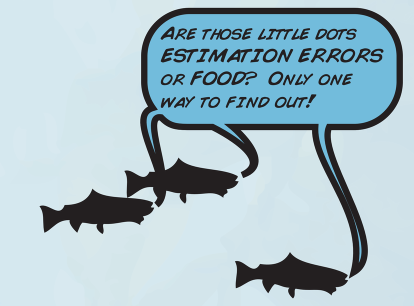


Figure 3. Slices from a synthetic image.



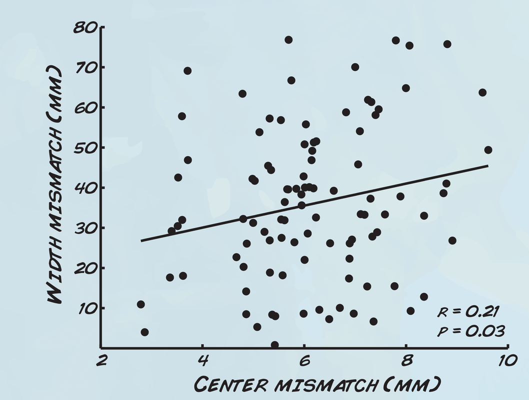


Figure 5. Node width estimation errors are correlated with node center estimation errors.

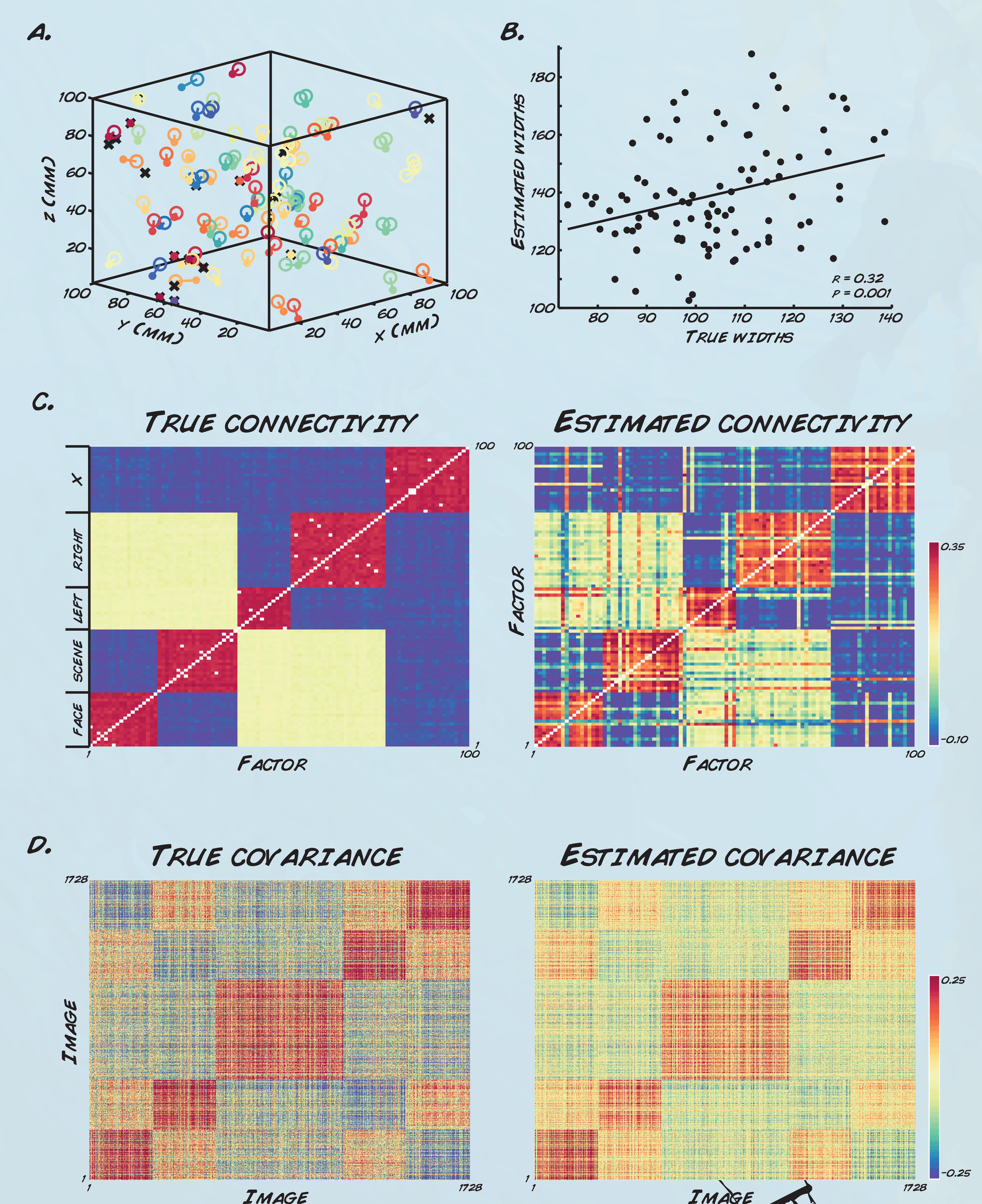


Figure 4. Recovering synthetic parameters. A. Node centers. B. Node widths. C. Node connectivity. D. Across-image covariance.

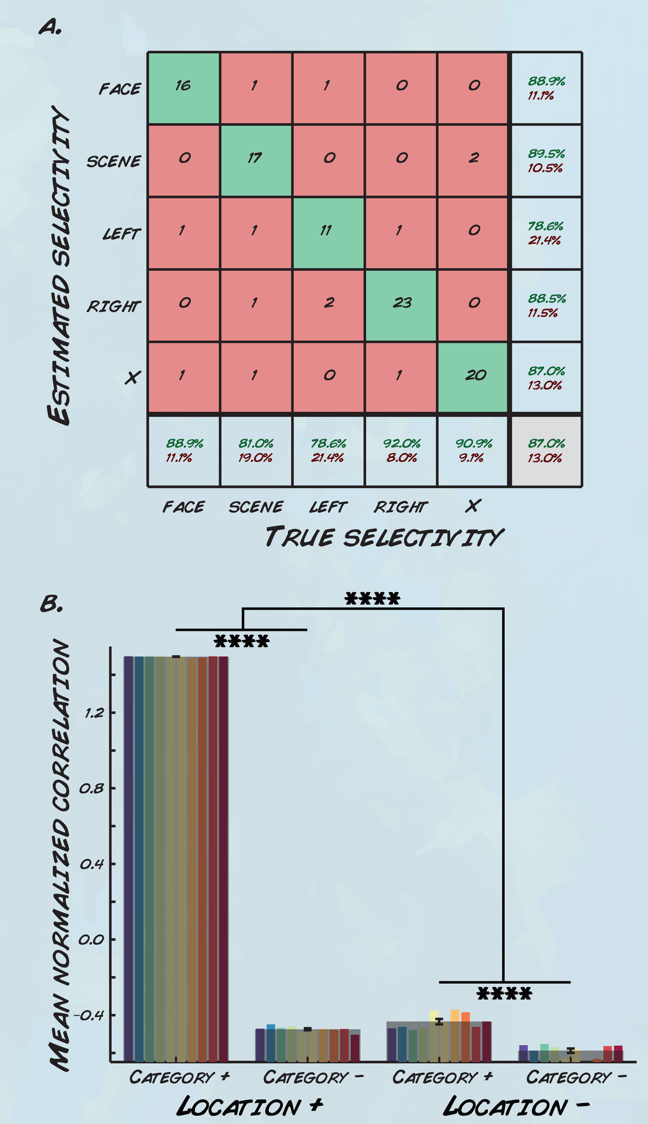


Figure 6. Recovering node selectivity and functional connectivity. A. Confusion matrix. B. Functional connectivity by experimental condition.

Using **simulated data**, the explorers test out their ideas. Against all odds, the first **glimmering parameters** are recovered successfully! Slowly, painstakingly, the crew begins an analysis of **real fMRI** data...

Results: Real Data

- We also applied **HTFA** to a **spatial attention** dataset collected by Nas Al-Aidroos, Alexa Tompary, and Nicholas Turk-Browne.

- We used localizer data to identify networks of nodes that exhibited **face**, **scene**, **left**, or **right** selectivity.

- We examined **background connectivity** between these networks during different experimental conditions. We found that the connectivity patterns were modulated with participants' attentional states.

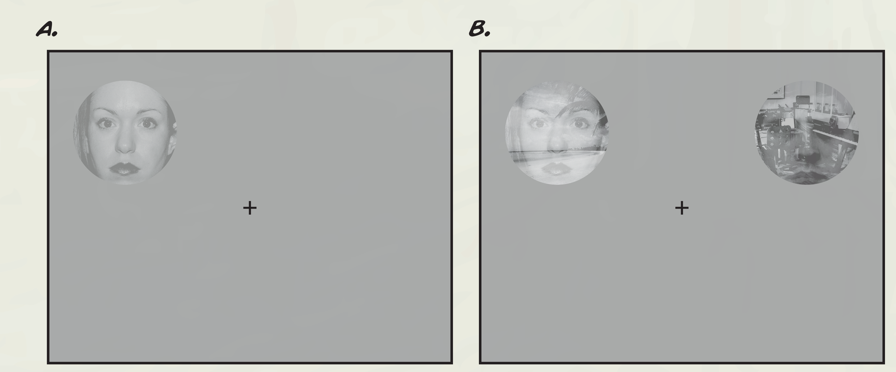


Figure 6. Spatial attention dataset. A. Localizer. B. Attention task.

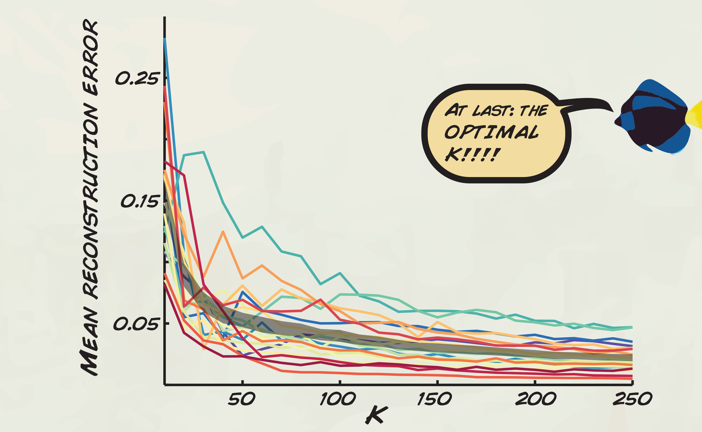


Figure 7. Determining the optimal number of nodes using cross-validated reconstruction error of connectivity patterns.

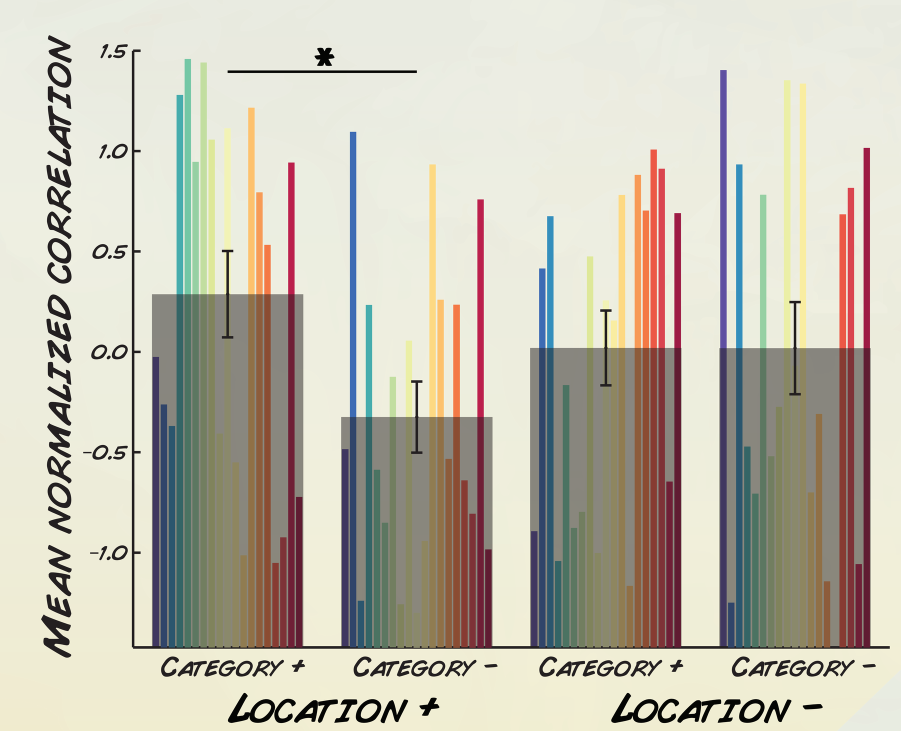
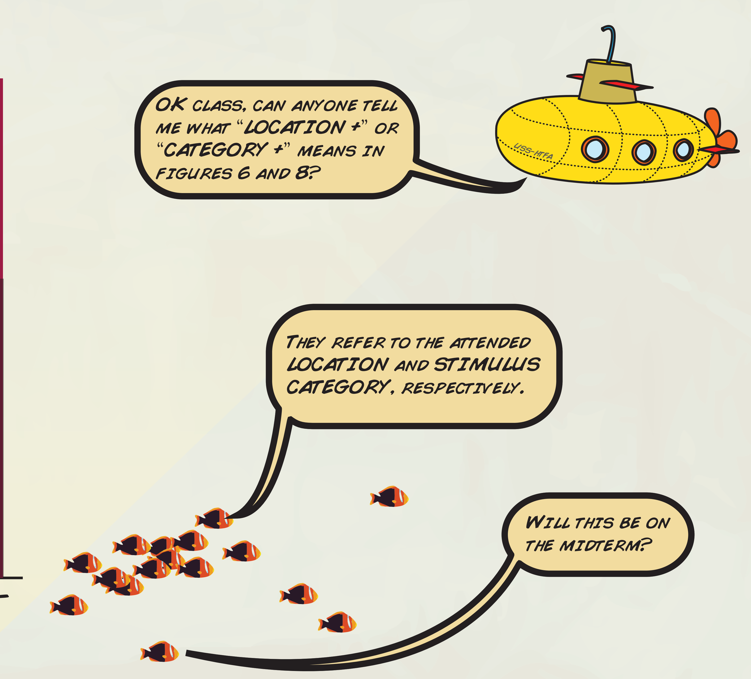


Figure 8. Functional connectivity by experimental condition.



The results begin to rise from the depths, and they are **glorious to behold**. Not only are the brain networks **fully functional**, but they are even **modulated by attention!** The crew will be "**science-rich**" beyond their wildest dreams!!

Conclusions

- The **compact HTFA**-derived network representations are much more efficient to compute with than voxel-based representations. This makes it easier to apply complex algorithms (e.g. **pattern classifiers**) to connectivity data.

Word of the crew's **fantastic journey** spreads **across the world**. Would-be explorers flock to www.princeton.edu/~manning3 to freely download the crew's source code. Will **you** be the next explorer to plumb these depths??