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Exploring the landscape of brain dynamics using topological data analysis

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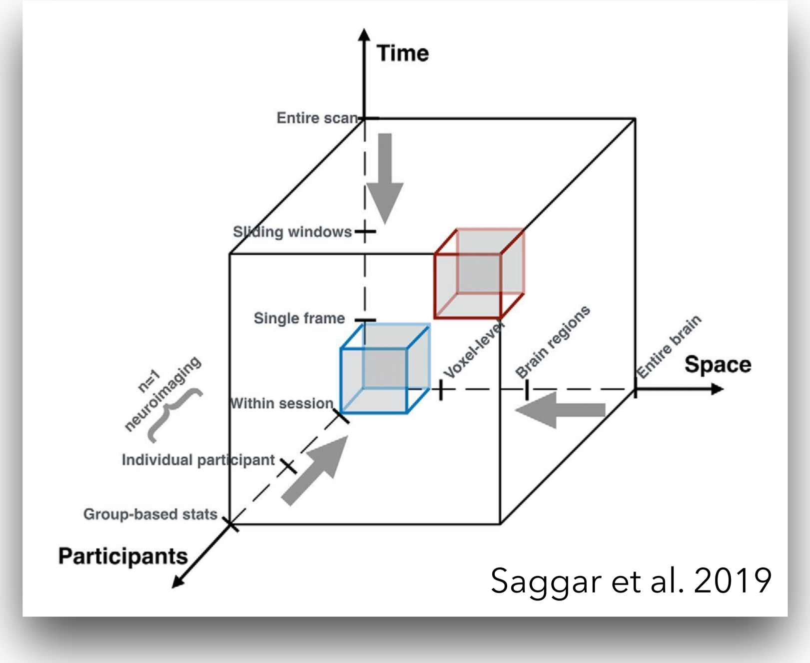
Motivation

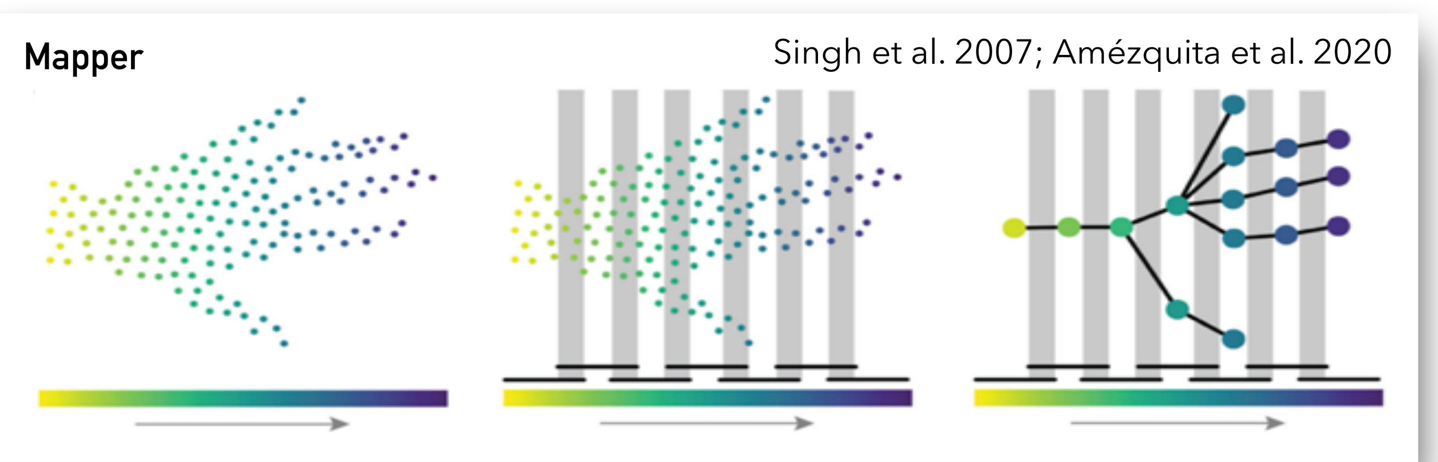
Most neuroimaging studies average data in time, space, and across subjects (**red cube**) ignoring potentially relevant information.

The Mapper algorithm from topological data analysis (TDA) can provide data-driven resolutions and insights about neuroimaging data at the individual-participant level and at the highest spatiotemporal resolution (**blue cube**) (Saggar et al. 2018).



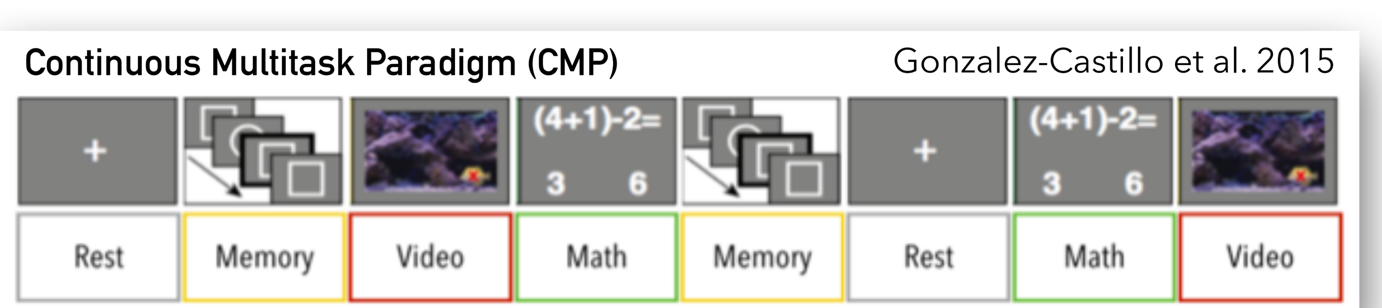
Towards improving clinical translation, this work addresses several limitations of the Mapper-based approach by (1) introducing a new nonlinear Mapper framework to allow for higher-dimensional embeddings of neuroimaging data, (2) automating parameter selection based on the autocorrelation structure of time-series data, and (3) showing how optimal transport can reveal novel insights about neurobiology and behavior.

Mapper provides interactive representations of neuroimaging data



- **Limitations** of Mapper
  - Requires **low-dimensional** embeddings, leading to **potential loss of information**
  - Requires **hand picking parameters**, with no established way to optimize/evaluate
  - Hard to generate **translational insights** from the Mapper representations
- Our **New Mapper Framework**
  - Stay in **high-dimensional** space to retain **more information**, using our new Mapper framework based on nonlinear dimension reduction
  - **Automated parameter selection** that leverages autocorrelation structure in time-series data (e.g., hemodynamic response function in fMRI)
  - **Optimal transport** analysis of **higher-order task interactions**, such as differences in the distributions of tasks across nodes in Mapper representations

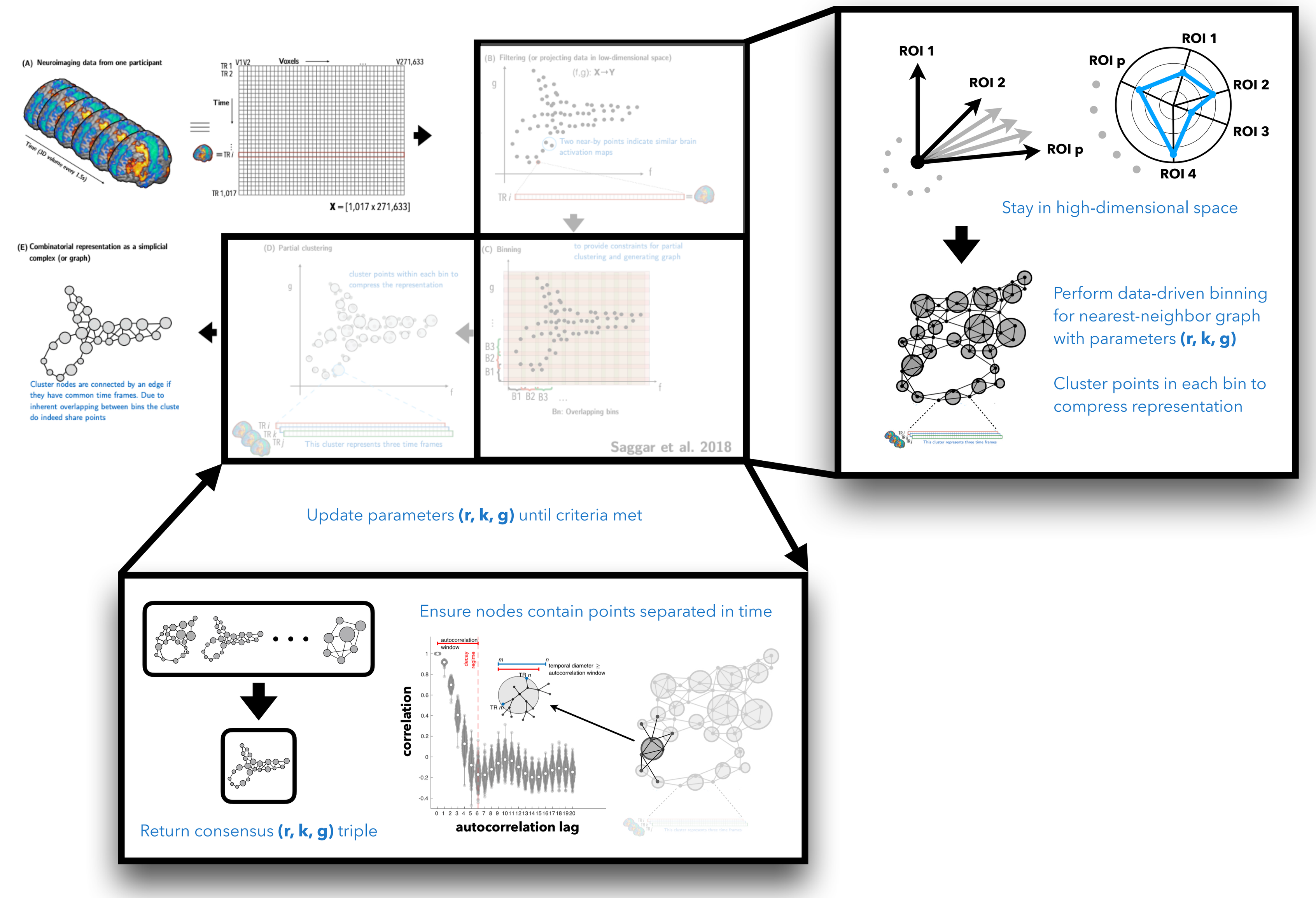
Continuous multitask fMRI dataset



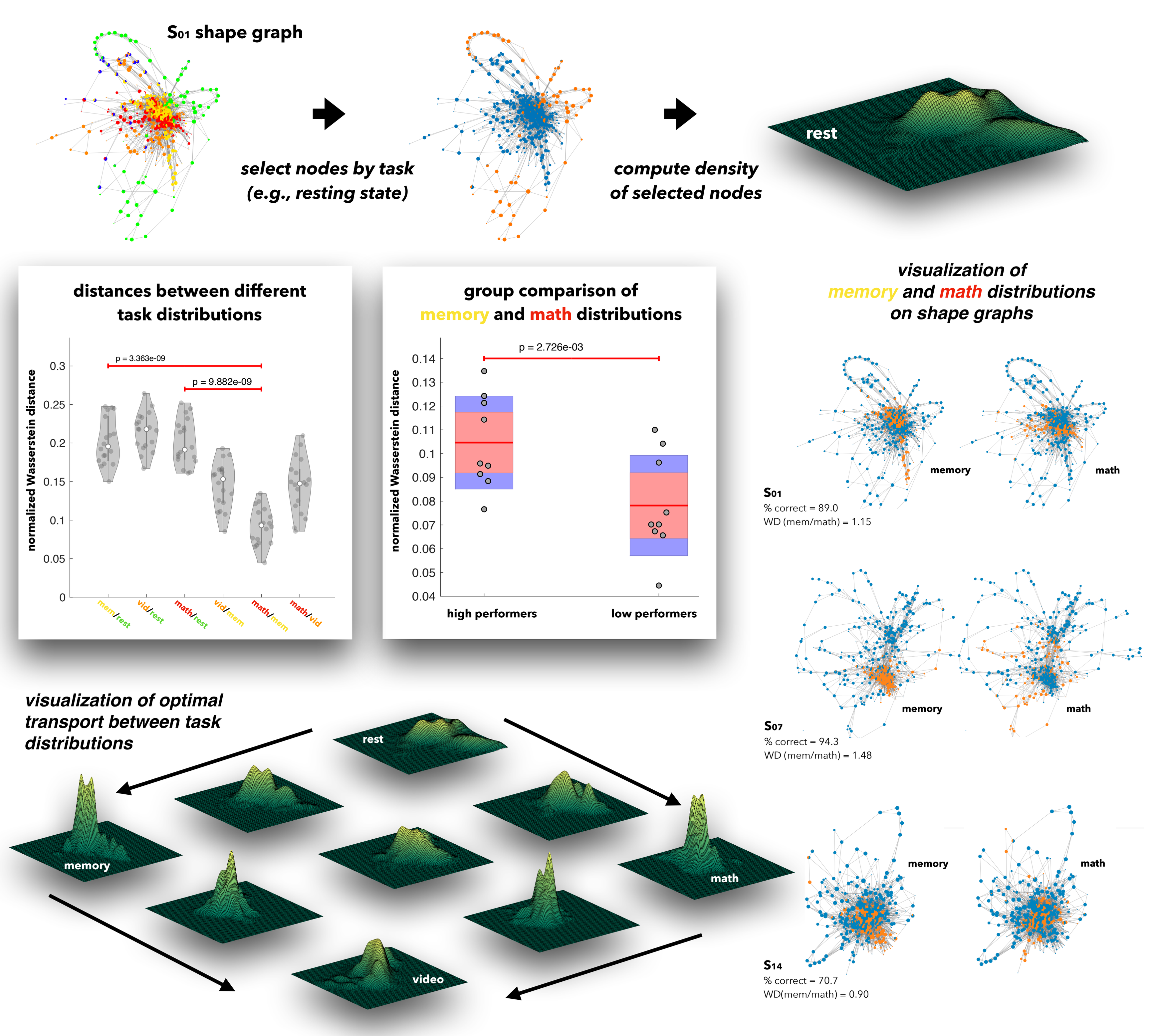
- Functional data from 18 participants acquired on a 7 Tesla MRI scanner (TR = 1.5 s)
- Average time-series were extracted from 375 ROIs after standard fMRI data preprocessing
- Behavioral data includes responses and reaction times for memory, video, and math

Results

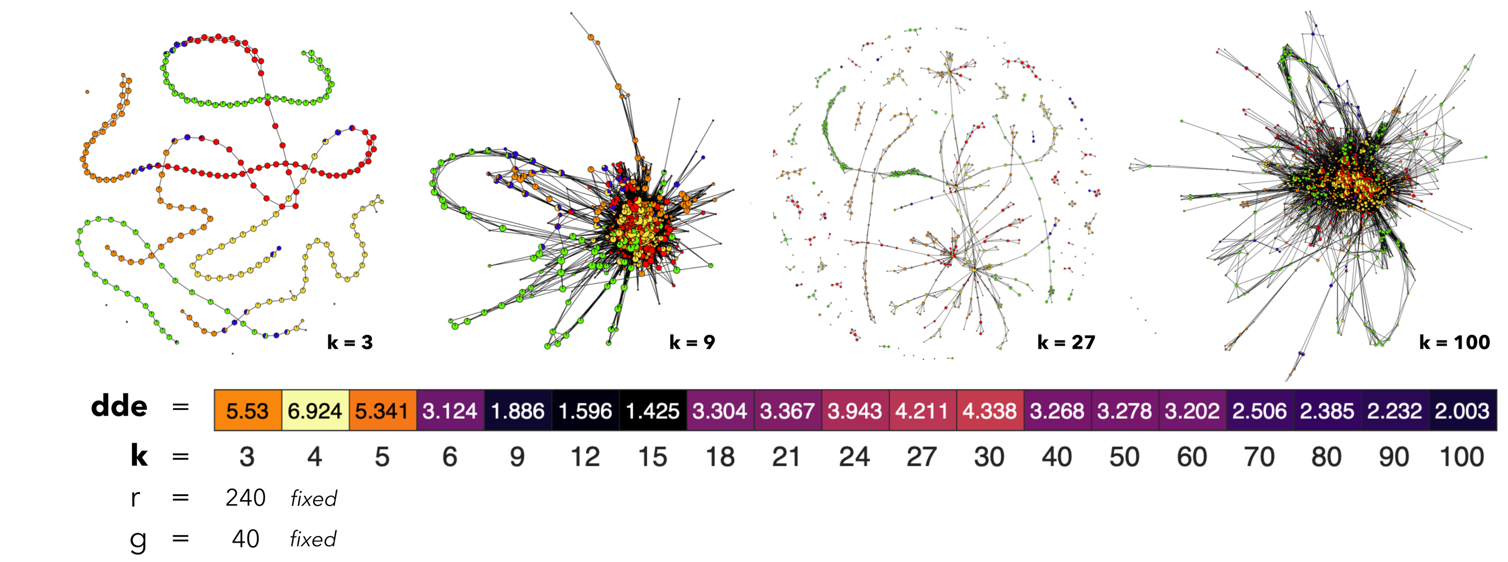
Nonlinear Mapper framework for neuroimaging applications



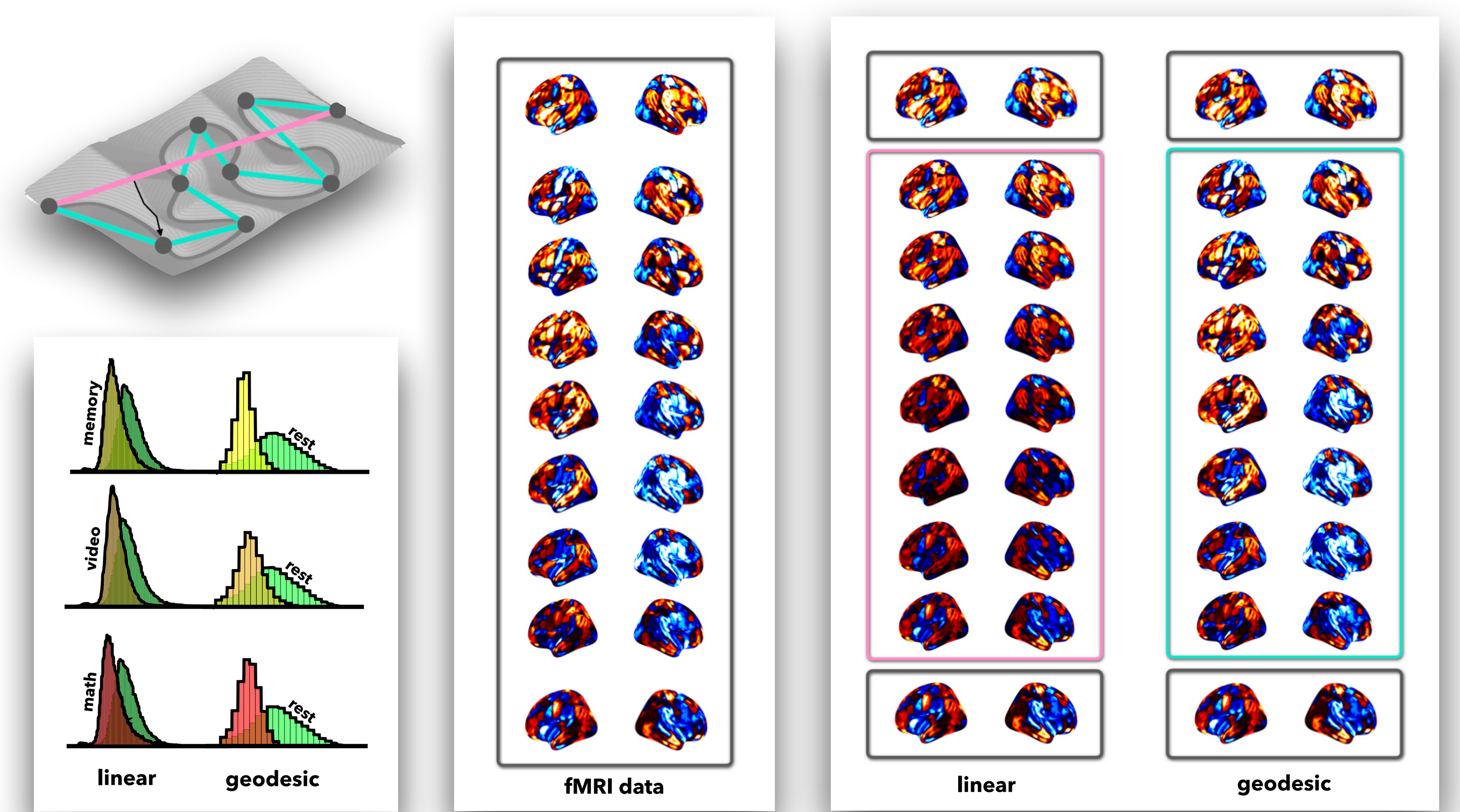
Optimal transport quantifies transitions between different tasks



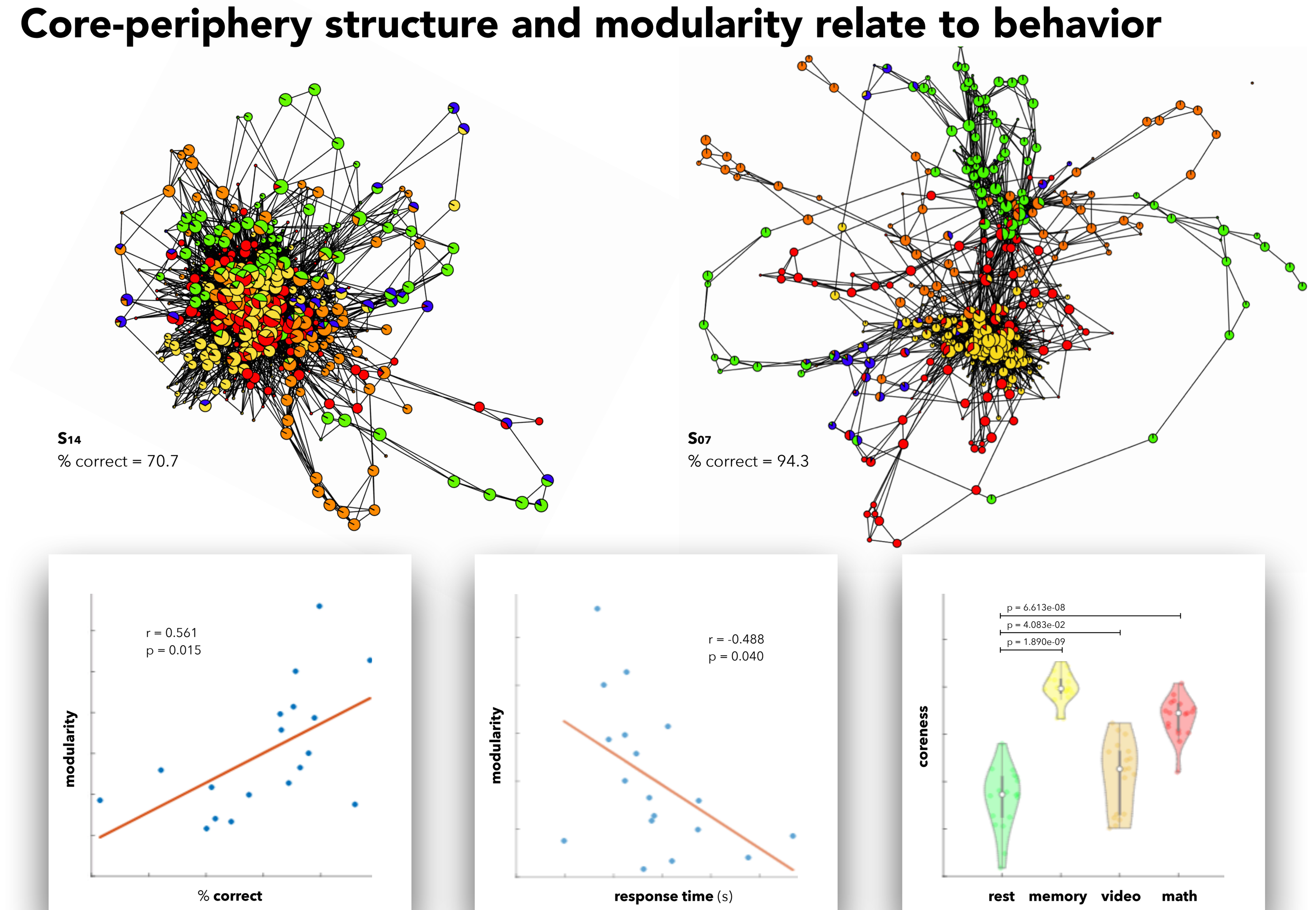
Distance distribution entropy varies across parameter space



Geodesic distances capture nonlinear structure of brain activity



Core-periphery structure and modularity relate to behavior



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