

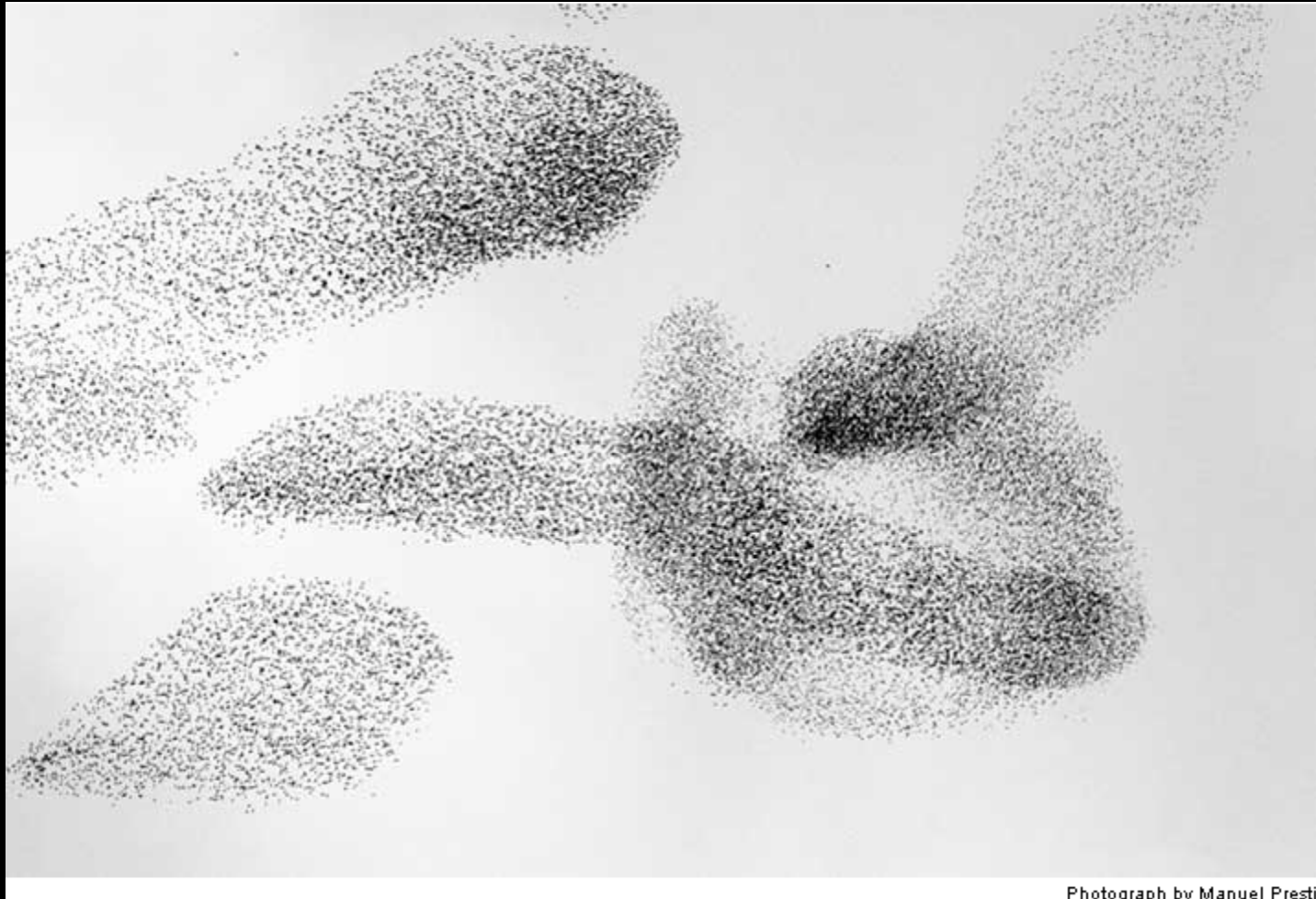
New Methods of Connectivity Analysis

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Professor
Department of Radiology



Wake Forest[™]
School of Medicine

Complex Systems



Photograph by Manuel Presti

Central Control



Central Control



Central Control



Central Control



Does chaos erupt in the absence of central command?

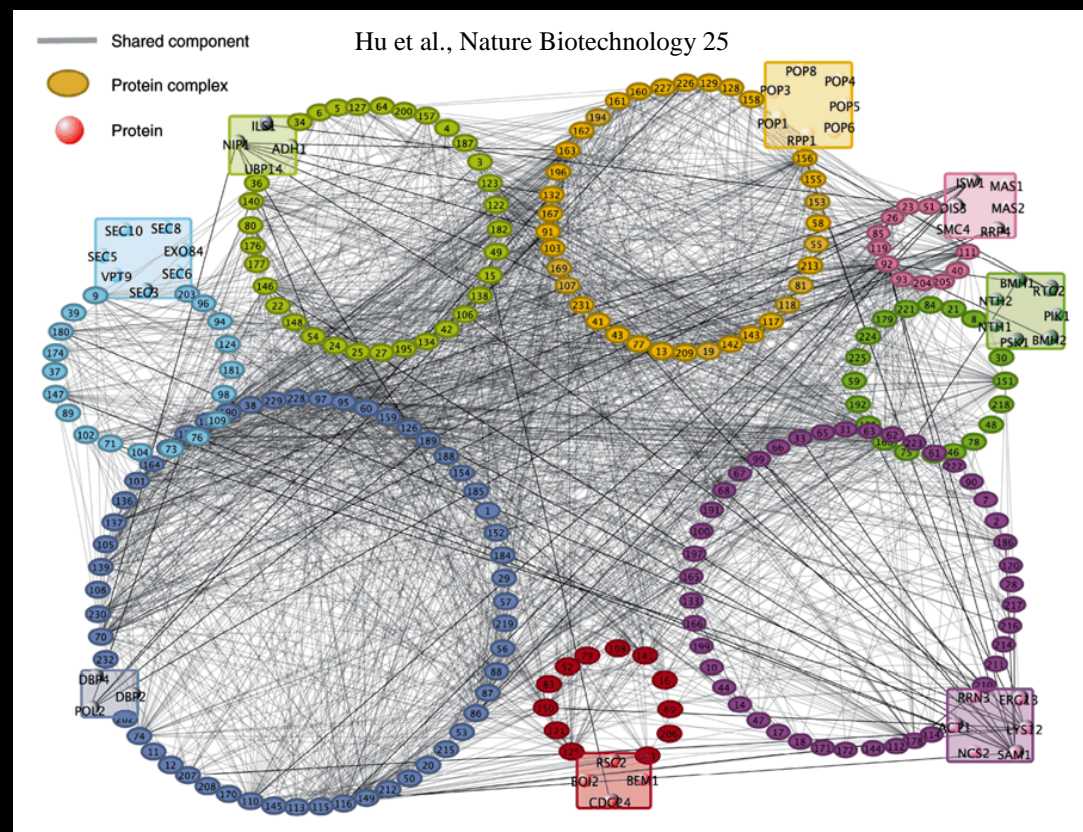




Emergence

Complex Systems

- Interconnected



Complex Systems

- Interconnected
- Interdependent

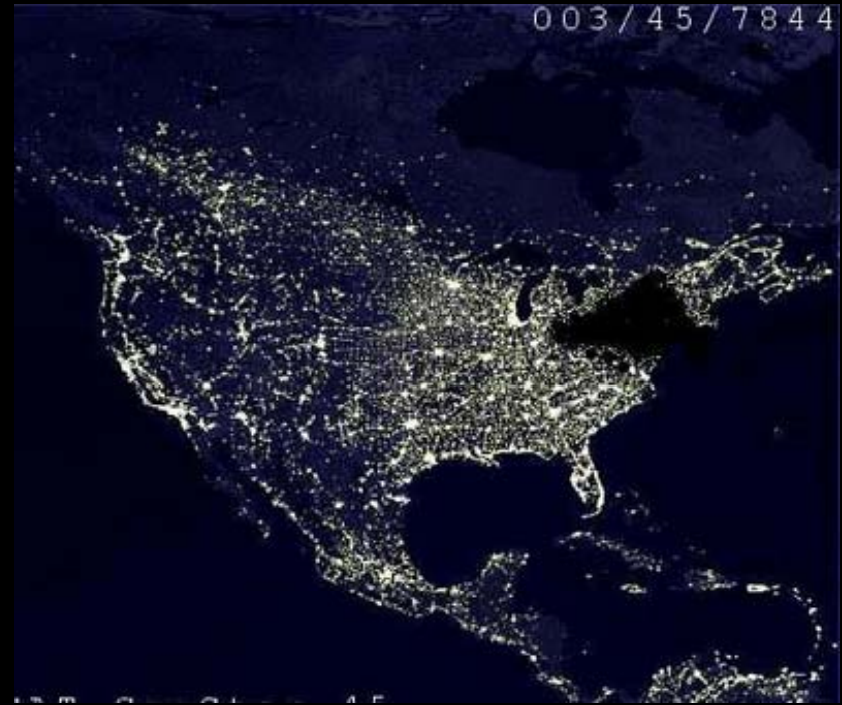


Complex Systems

- Interconnected
- Interdependent



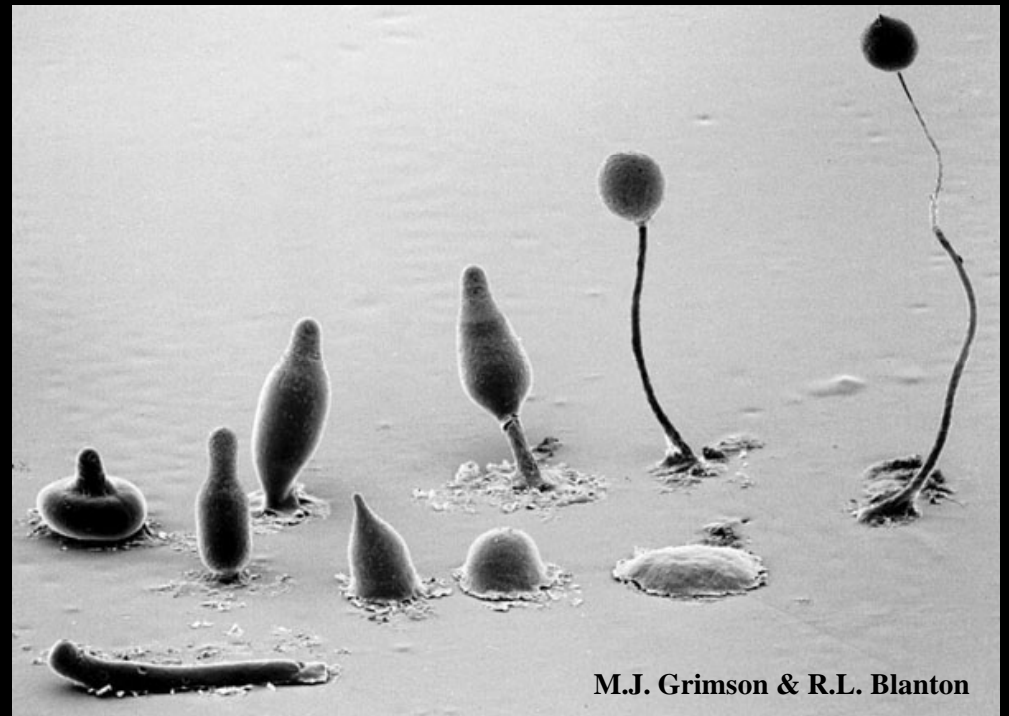
www.geology.com



www.nyc.metablogs.com

Complex Systems

- Interconnected
- Interdependent
- Adaptive



M.J. Grimson & R.L. Blanton

Complex Systems

- Interconnected
- Interdependent
- Adaptive
- Diverse



Ins and Outs of the Science of Emergence

- IN

- Systems analysis
- Interacting elements
- Power laws
- Information theory
- Statistical physicists
- Networks
- Methods development
- Innovative thought

- OUT

- Reductionism
- Independence
- Normal distribution
- T-tests/correlations
- Biostatisticians
- ROIs
- Black-box software
- Boring research

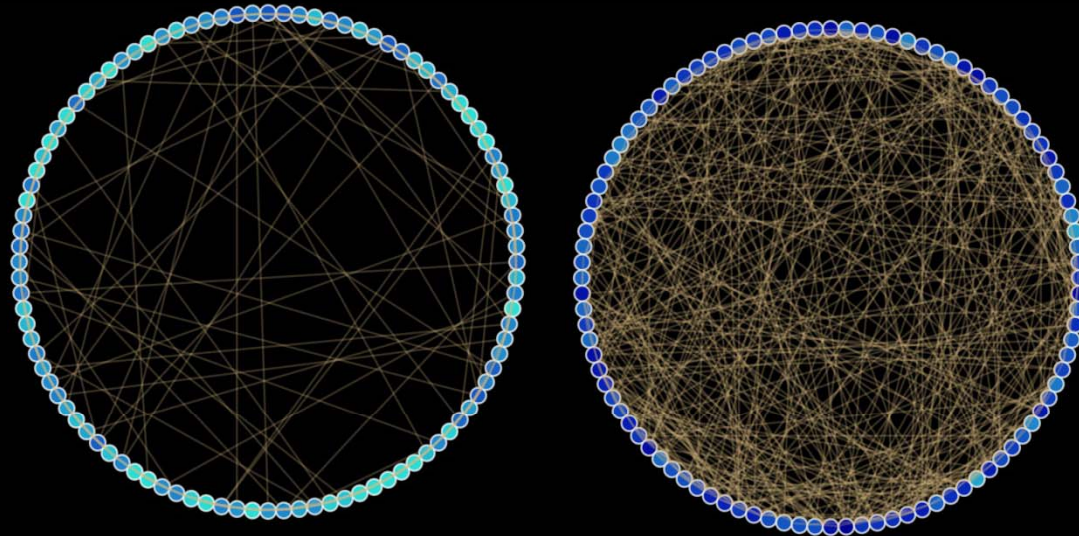
Complex Brain Networks

What does clustering, path length, or degree really tell us about brain processing?

100 nodes

Mean degree = 8

$L=2.8$ vs. $L=2.3$



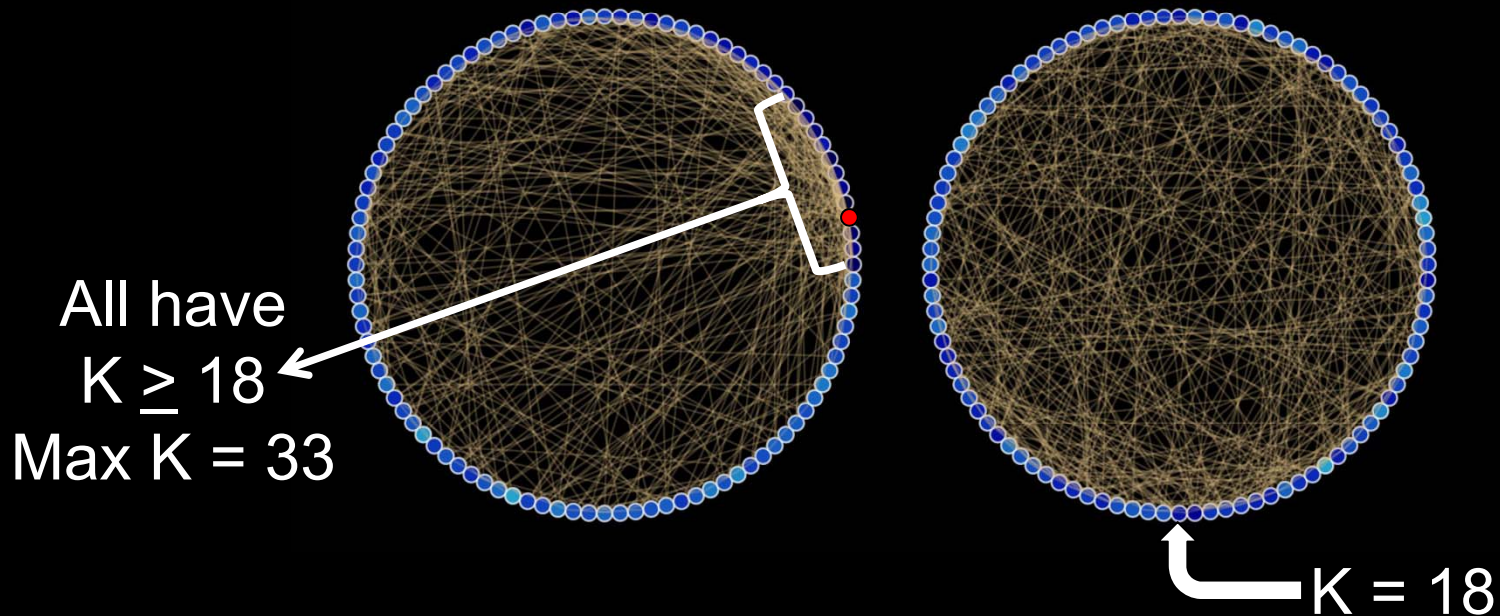
Complex Brain Networks

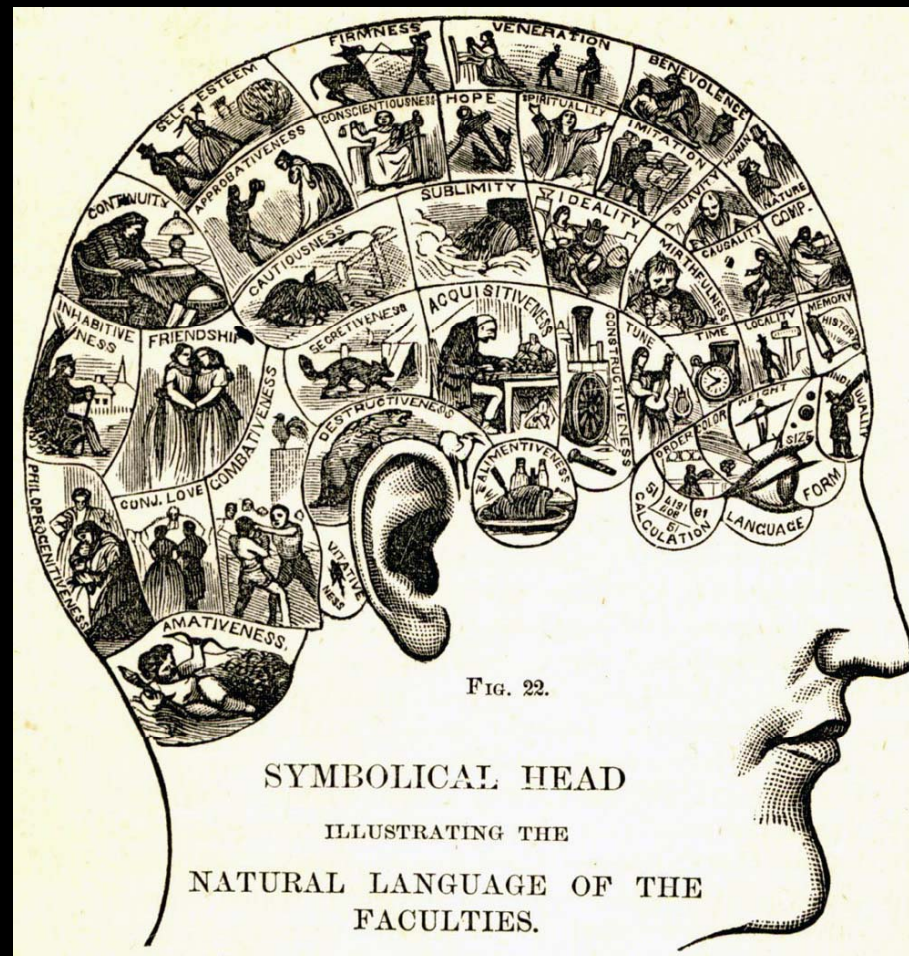
What does clustering, path length, or degree really tell us about brain processing?

100 nodes

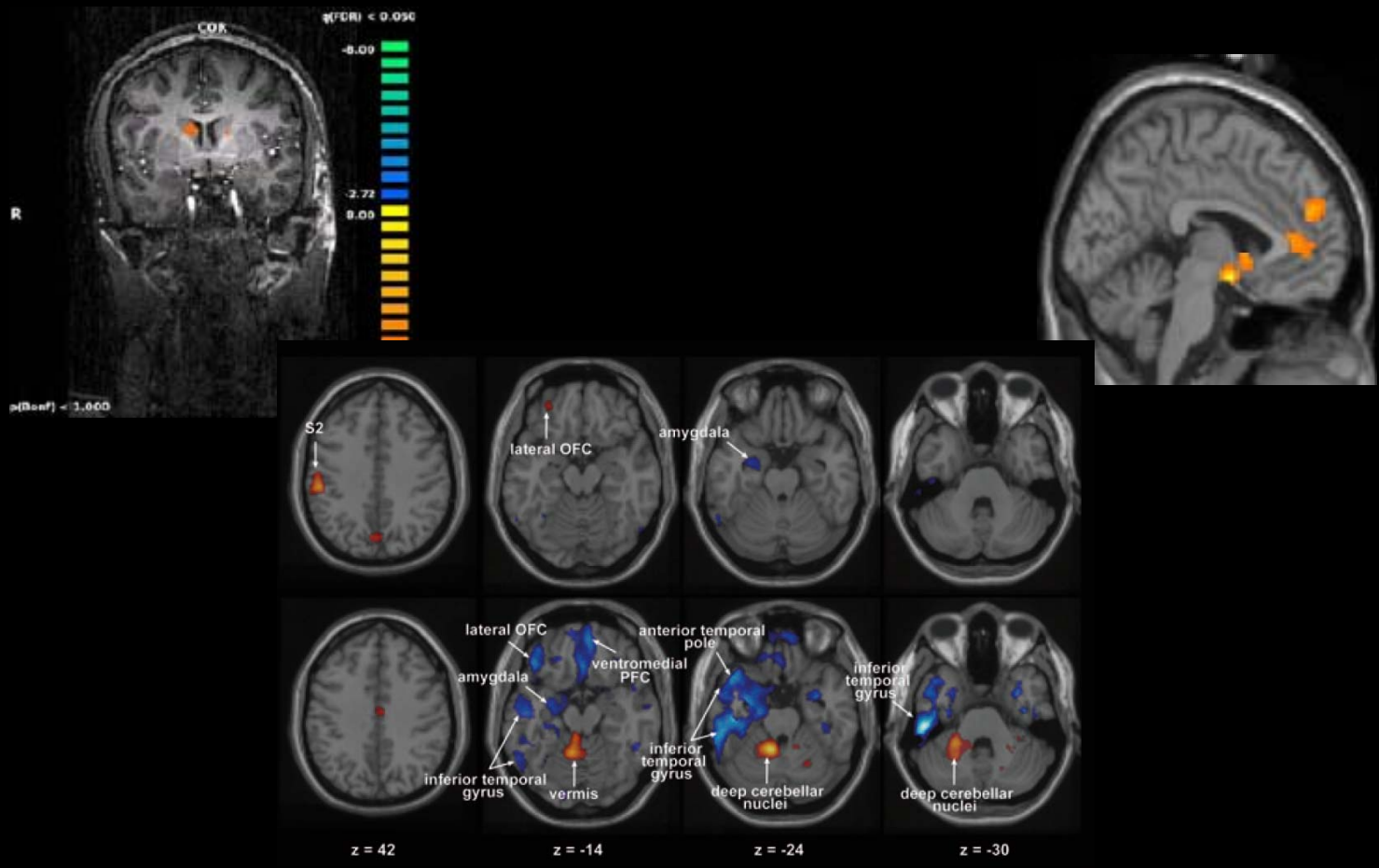
Mean degree = 8

$L \sim 2.3$ and $C \sim 0.1$

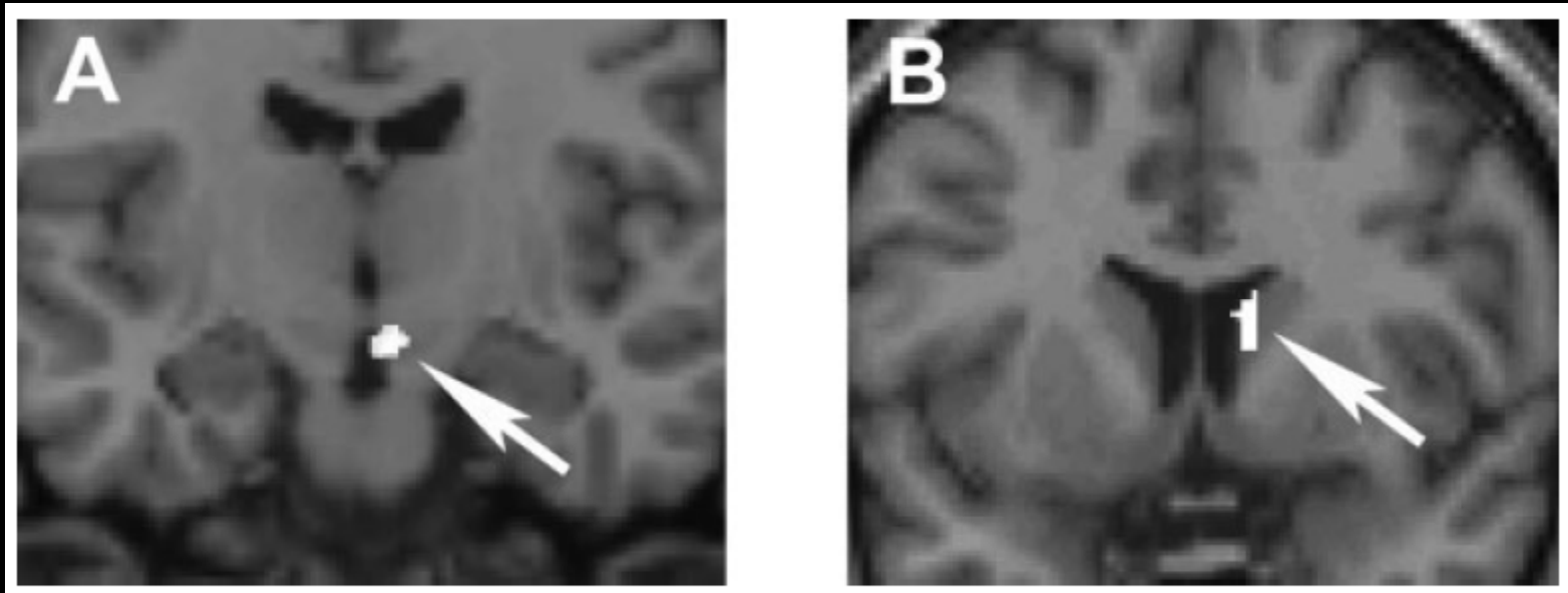




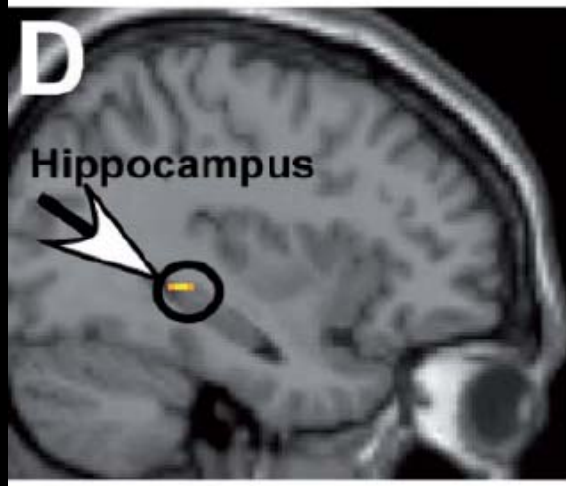
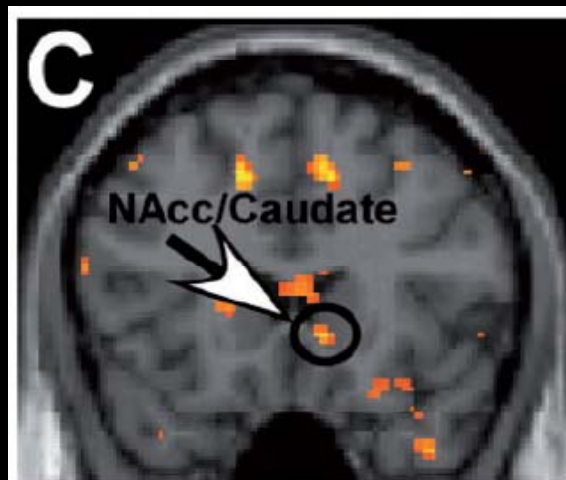
What we really want to know is how information processing in the brain produces perceptions, knowledge, consciousness, etc.



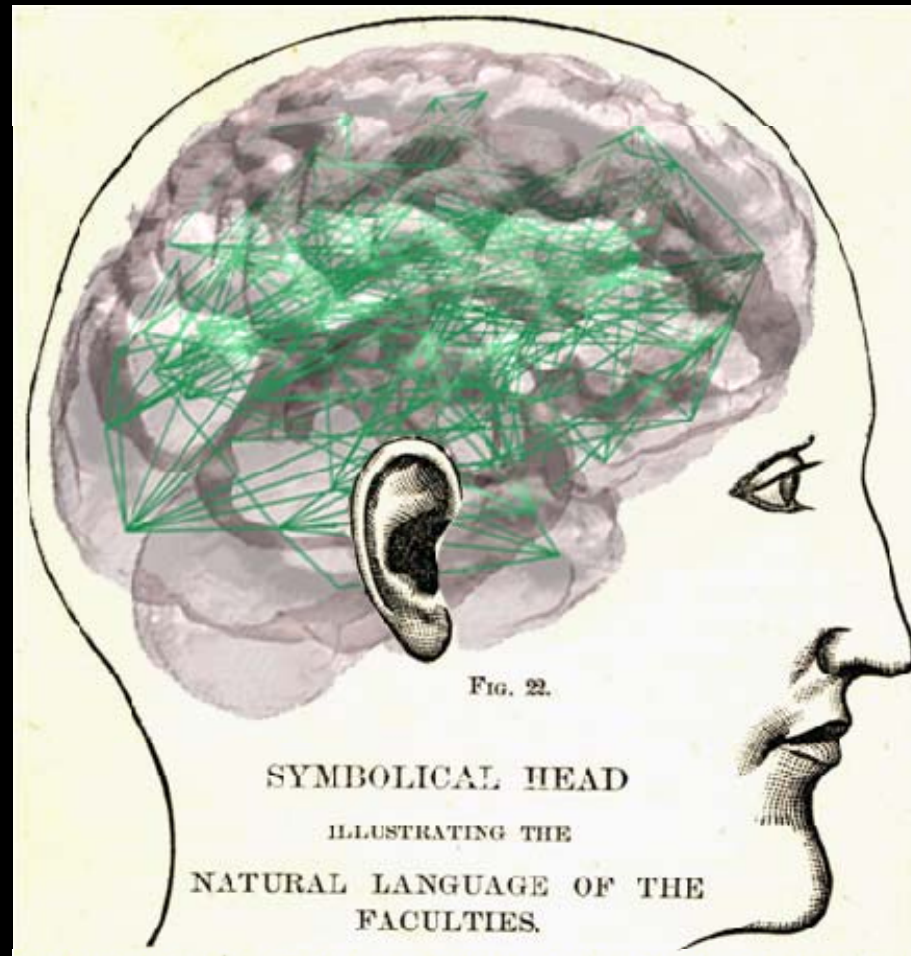
The neural basis of sexual arousal.
The brain regions for amativeness



The neural basis of romantic love.
The brain regions for conjugal love.

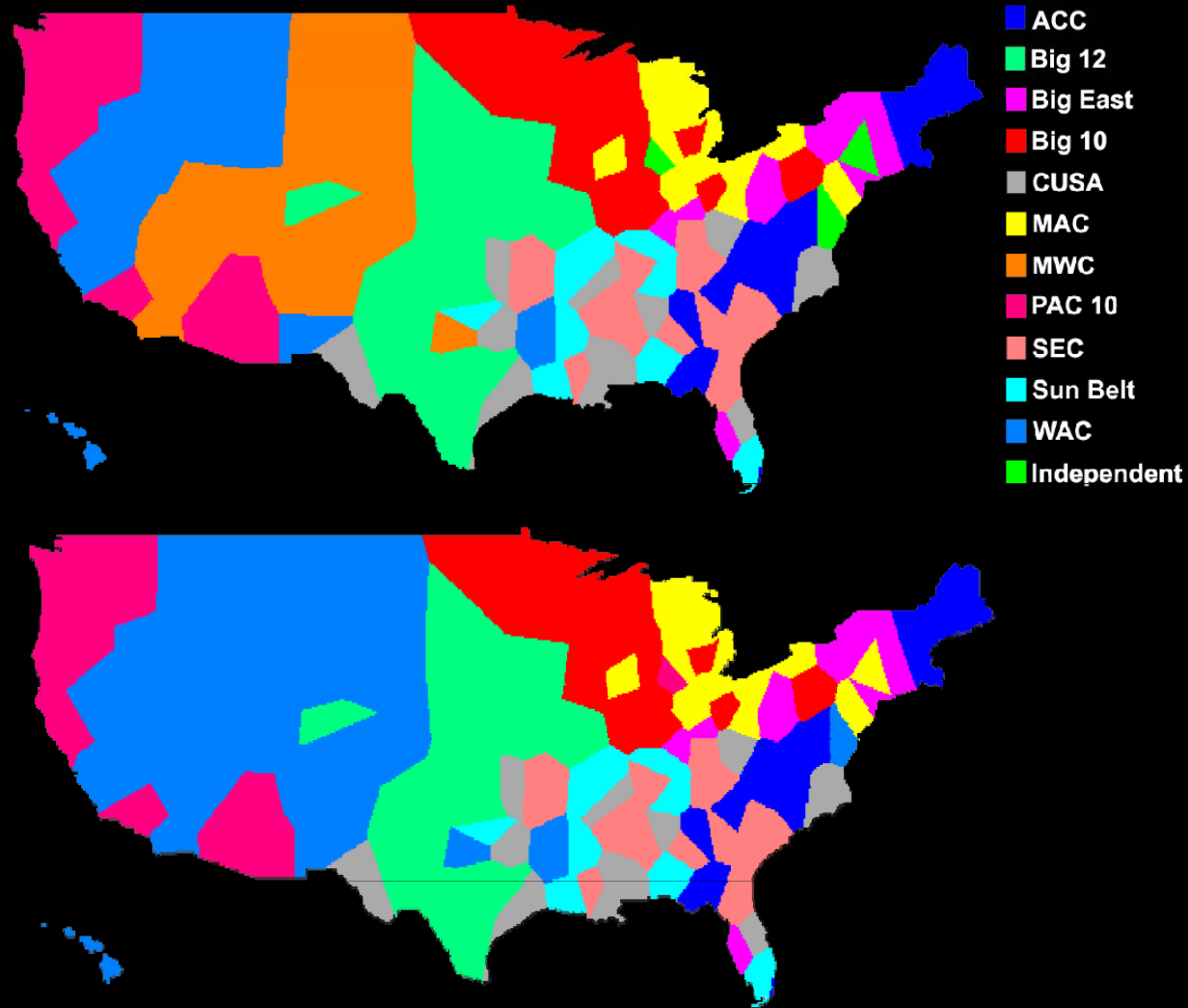


The neural basis of romantic love.
The brain regions for conjugal love.



Complex cognitive and emotional processing occurs through interactions between multiple sub-networks (or communities) within the brain.

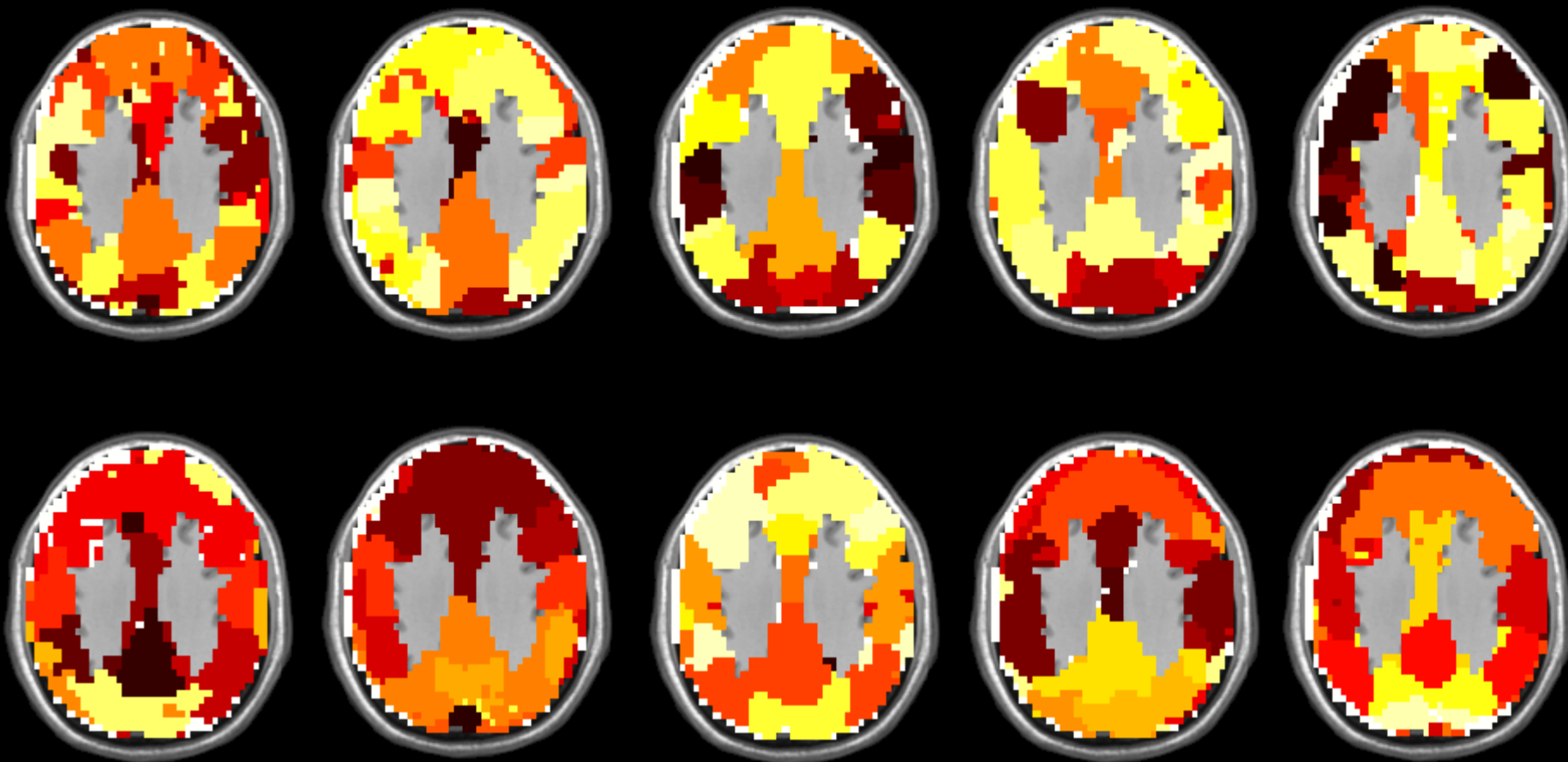
Community Structure



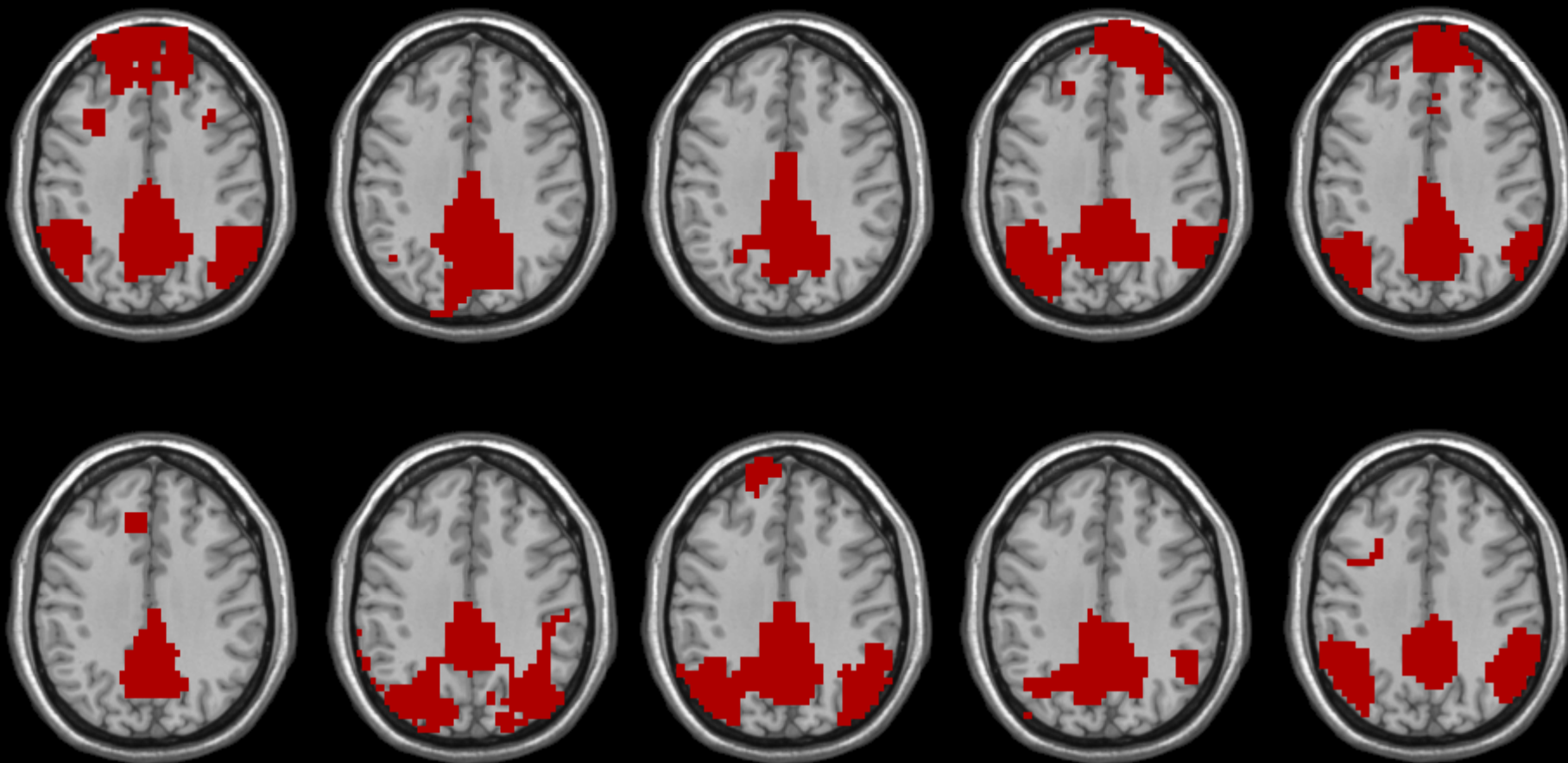
Brain Communities



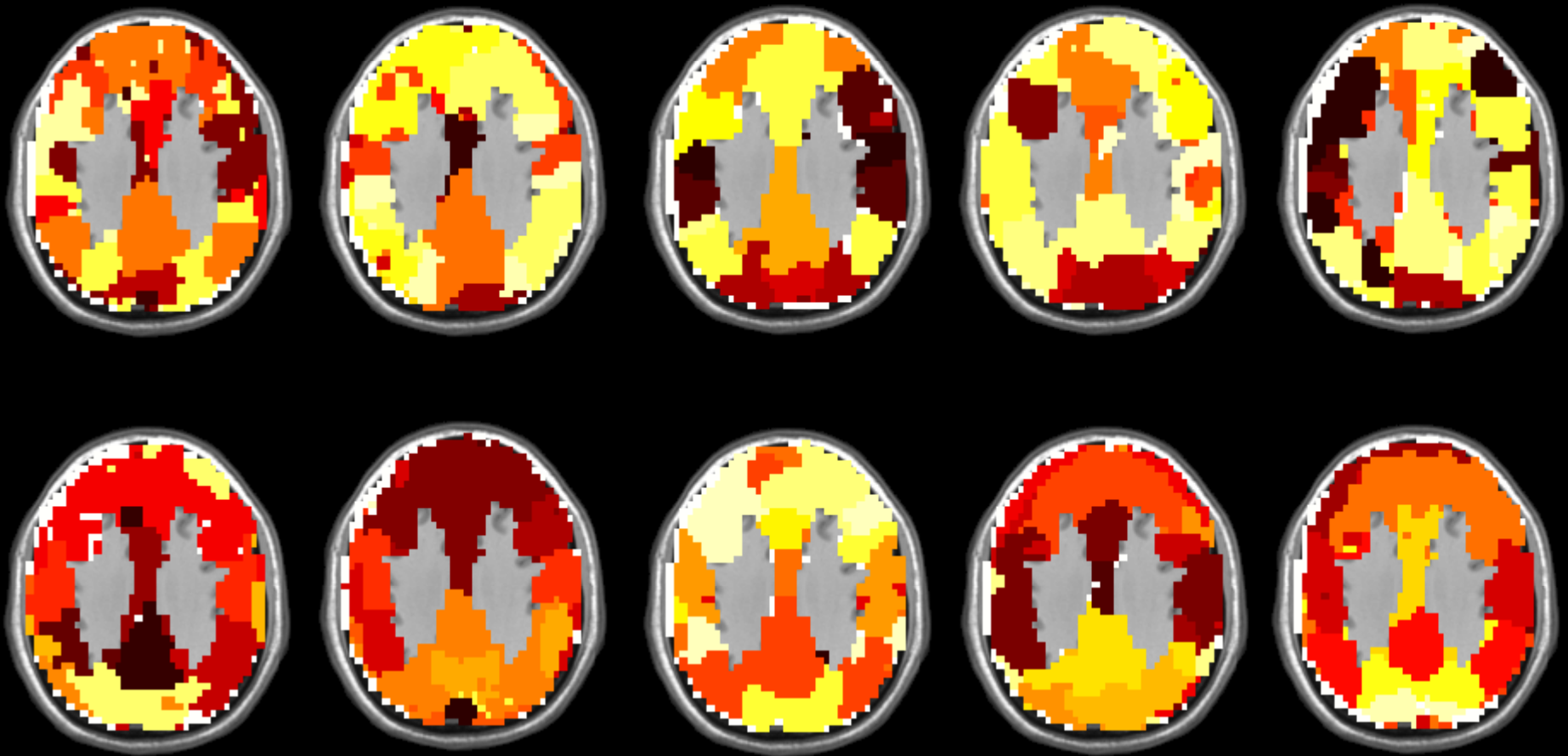
Brain Communities



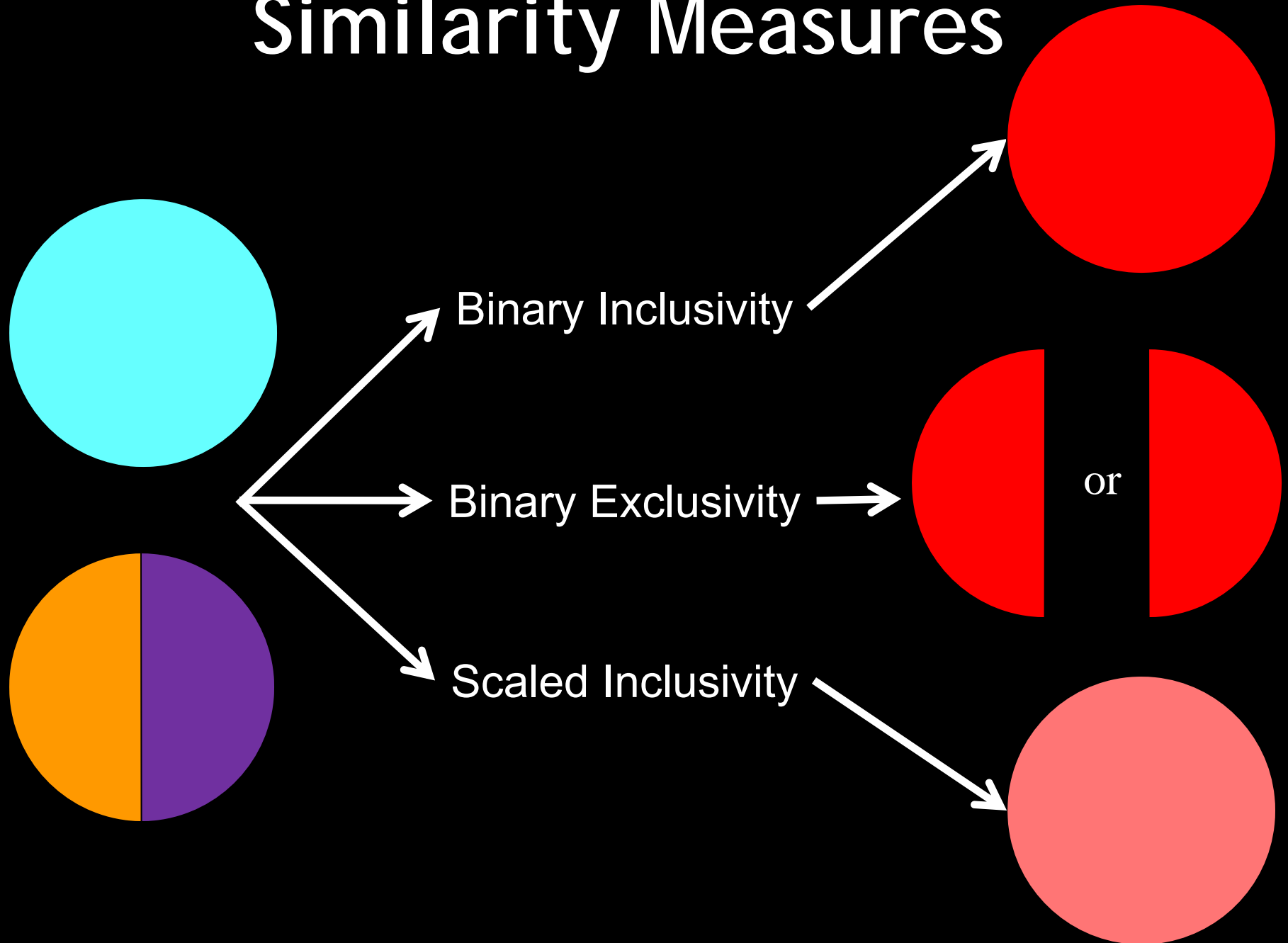
Precuneus Community



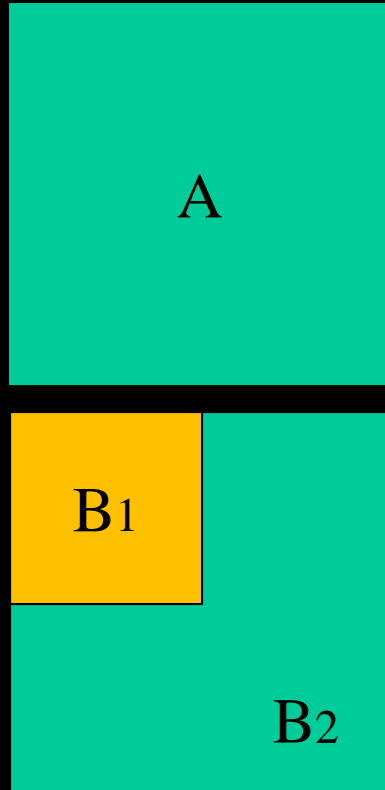
Across Subject Comparisons



Similarity Measures



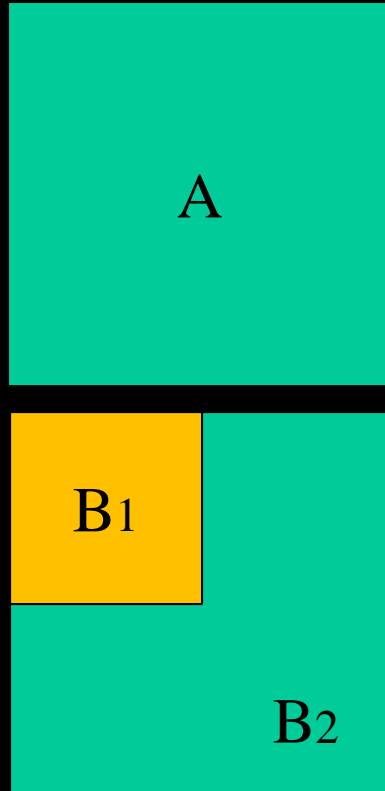
Scaled Inclusivity



$$\begin{aligned} \sigma_{\text{incl}}(\mu, E) &= \sigma_{\text{incl}}(\mu, E) \\ &- \frac{2\eta}{1-\mu} \text{Re} \left\{ \exp \left(\eta \ln \frac{1-\mu}{2} \right) \sum_{\ell=0}^{\infty} \frac{2\ell+1}{2} a_{\ell}(E) P_{\ell}(\mu) \right\} \\ &+ \sum_{\ell=0}^{\infty} \frac{2\ell+1}{2} b_{\ell}(E) P_{\ell}(\mu) \end{aligned}$$

$$\begin{aligned} \sigma_{\text{incl}}(\mu, E) &= \sigma_{\text{incl}}(\mu, E) \\ &- \frac{2\eta}{1-\mu^2} \text{Re} \left\{ \sum_{\ell=0}^{\infty} \left[(1+\mu) \exp \left(\eta \ln \frac{1-\mu}{2} \right) \right. \right. \\ &+ \left. \left. (-1)^{\ell} (1-\mu) \exp \left(\eta \ln \frac{1+\mu}{2} \right) \right] \frac{2\ell+1}{2} a_{\ell}(E) P_{\ell}(\mu) \right\} \\ &+ \sum_{\ell=0}^{\infty} \frac{4\ell+1}{2} b_{\ell}(E) P_{\ell}(\mu) \end{aligned}$$

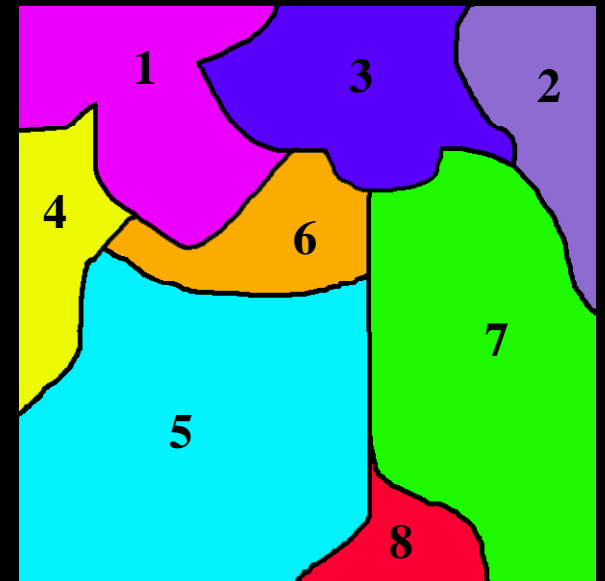
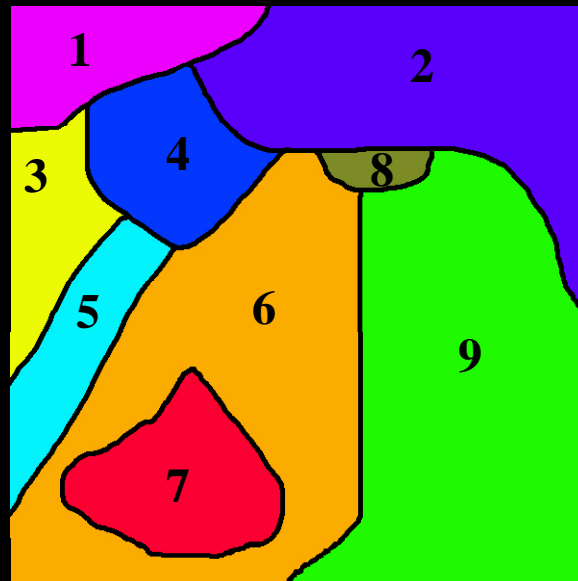
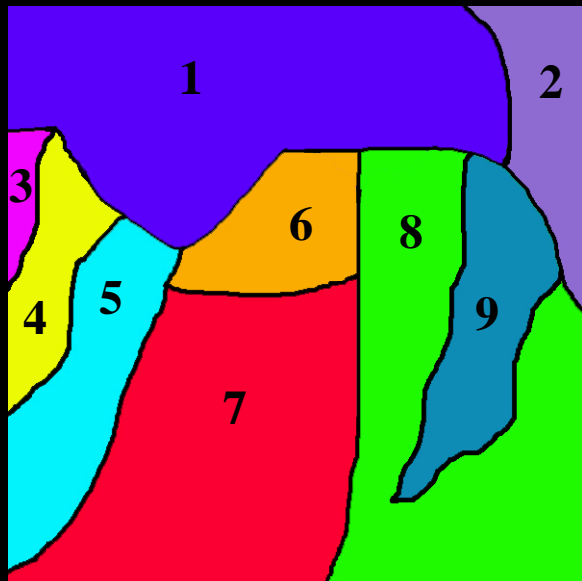
Scaled Inclusivity



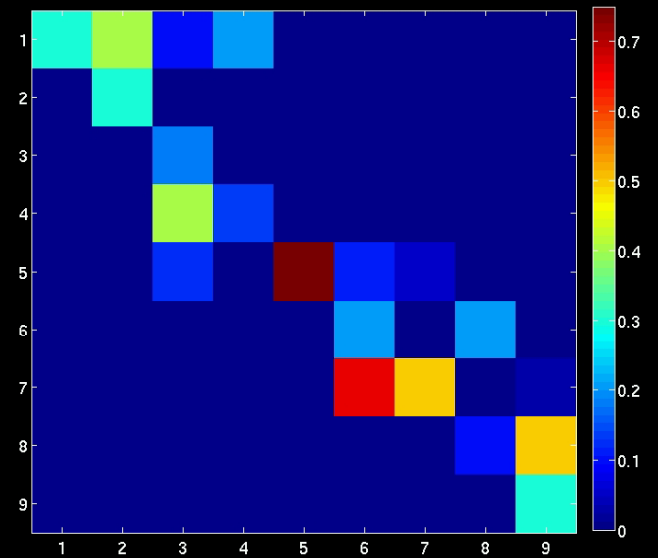
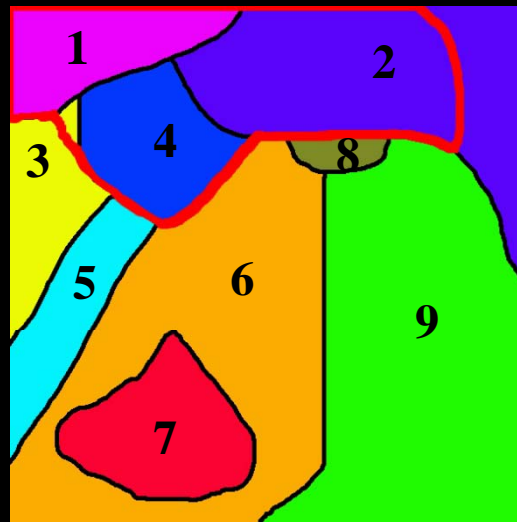
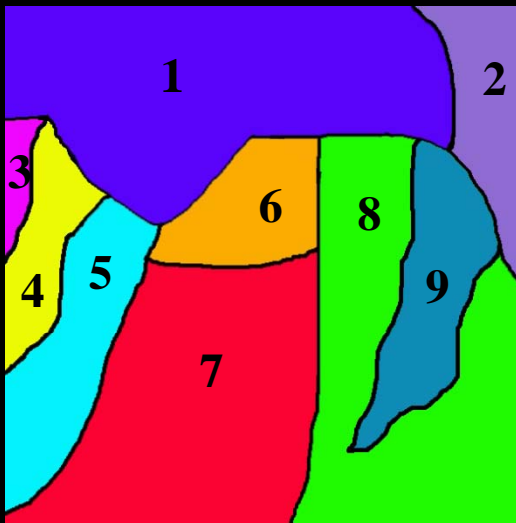
$$\frac{A \cap B_1}{A} * \frac{A \cap B_1}{B_1}$$

$$\frac{.25}{1} * \frac{.25}{.25} = .25$$

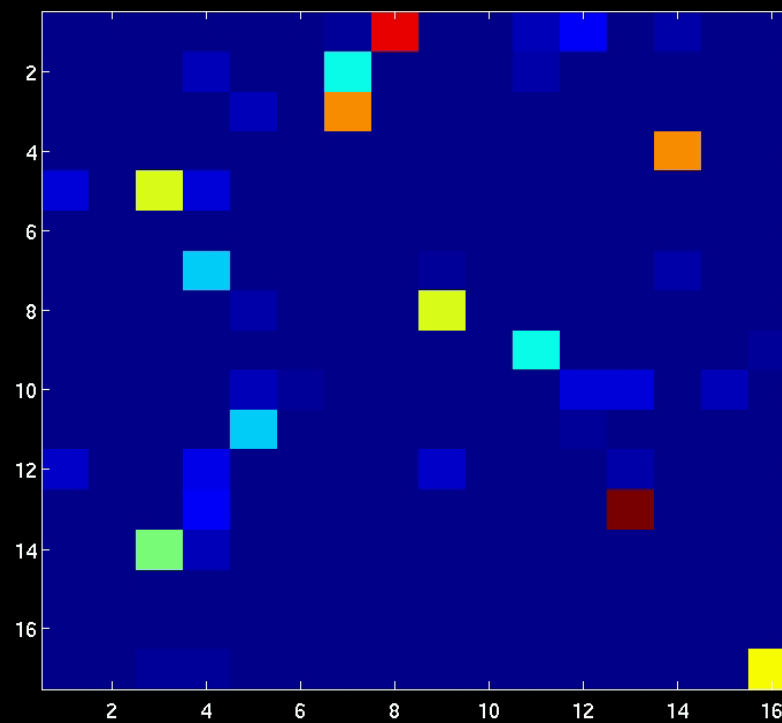
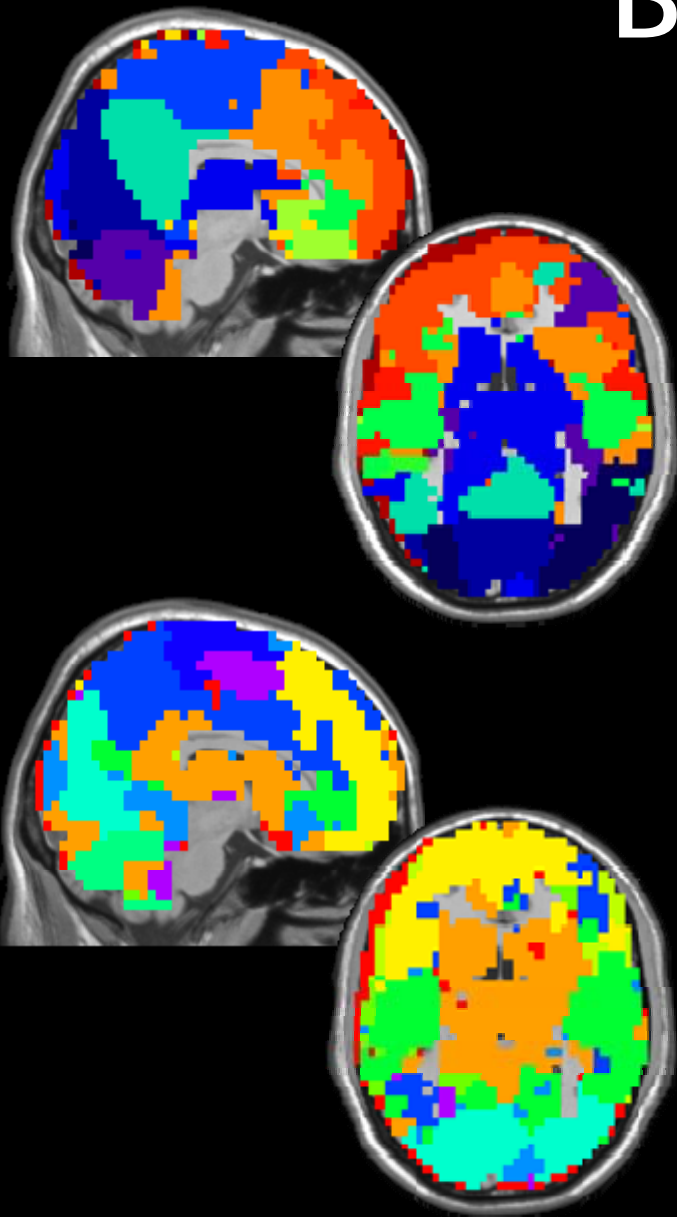
Community Similarity



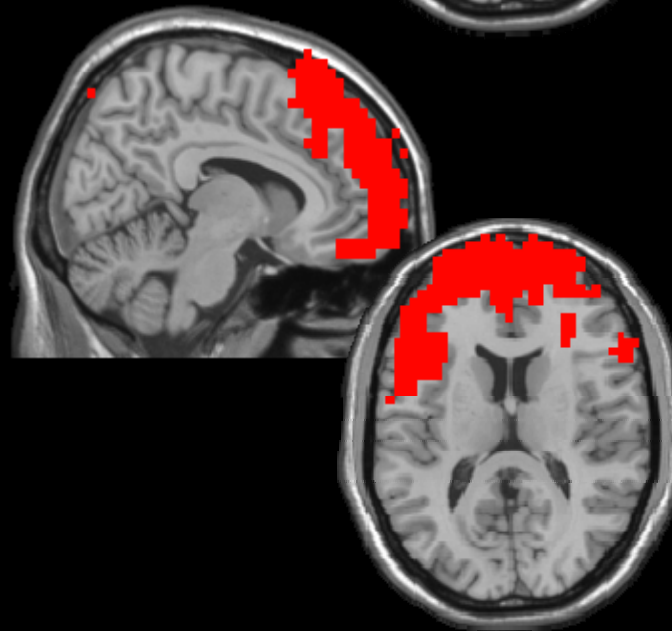
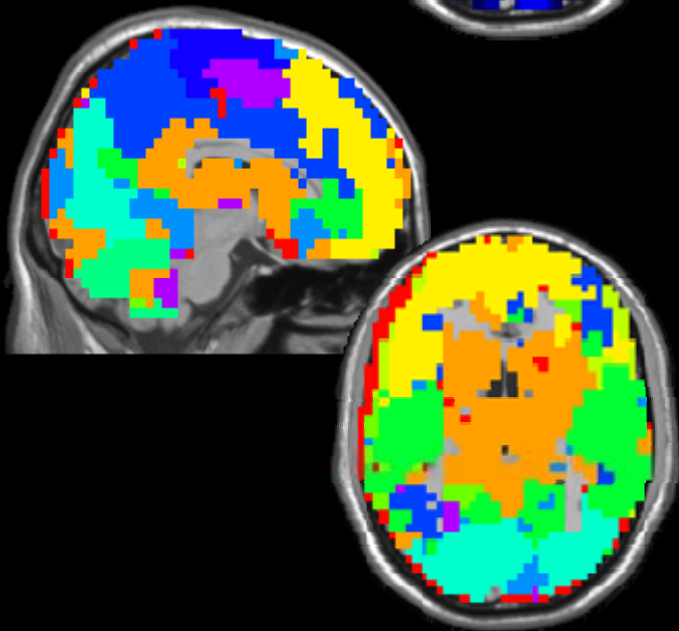
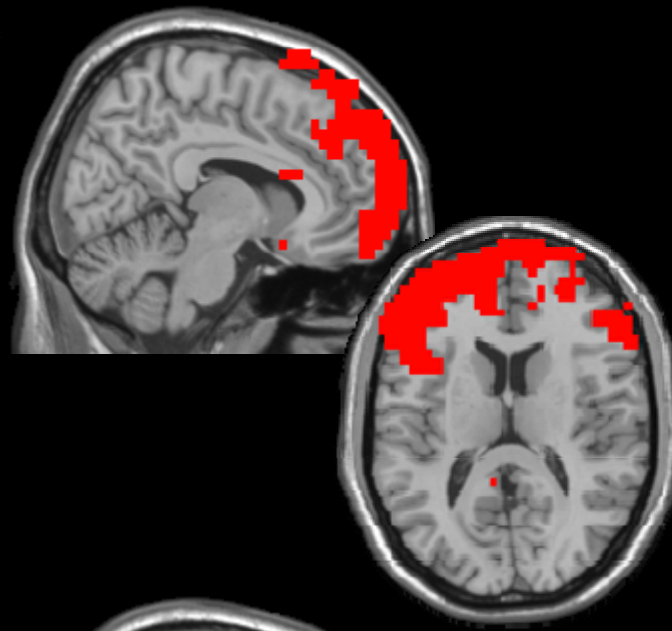
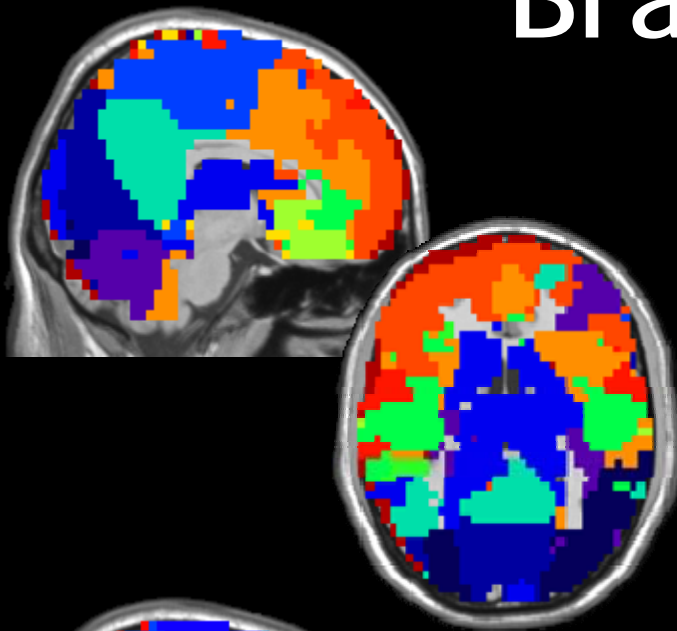
Scaled Inclusivity



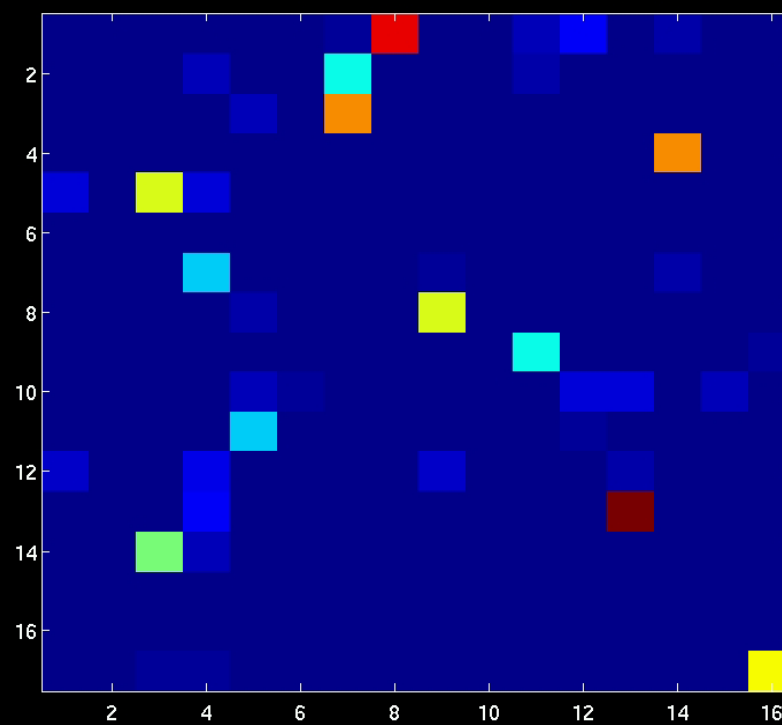
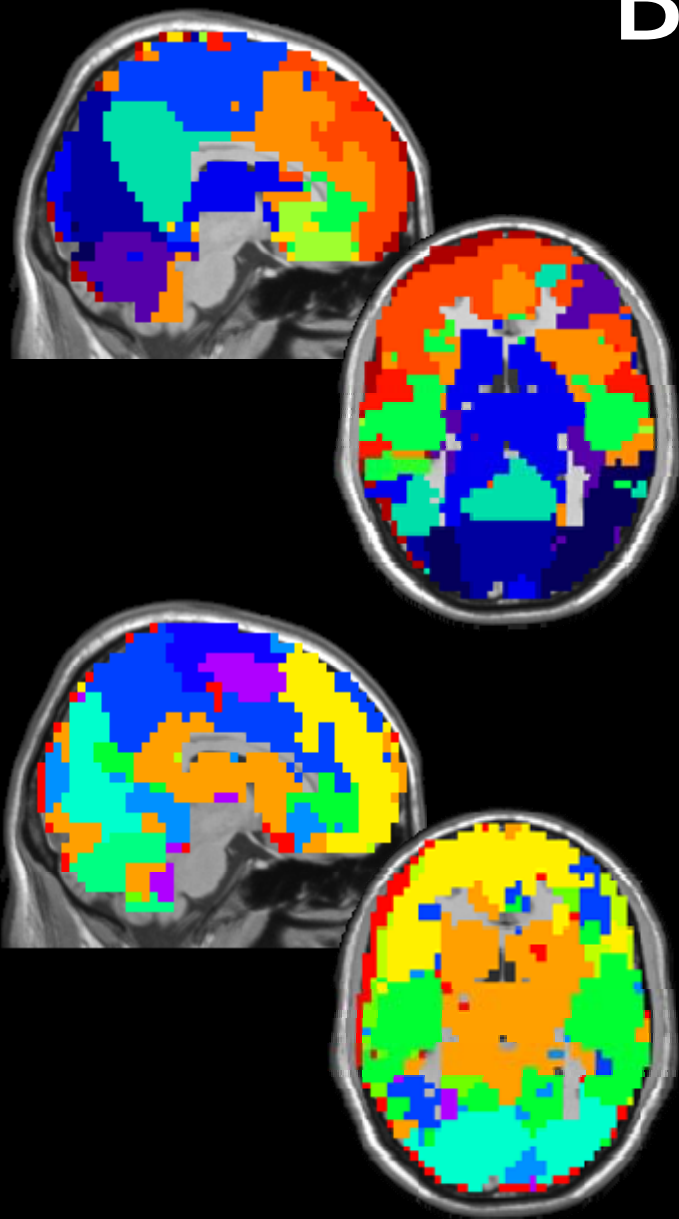
Brain Data



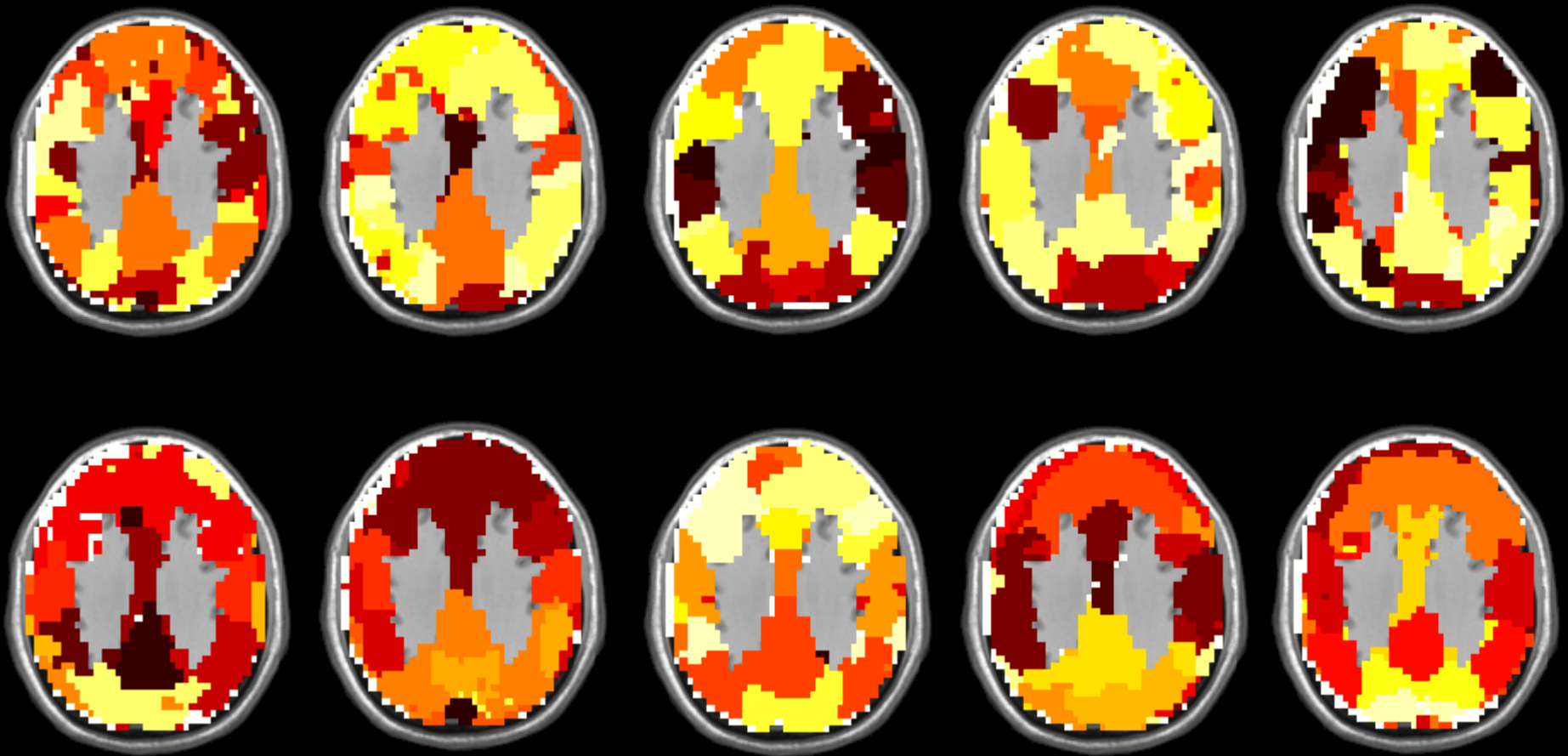
Brain Data



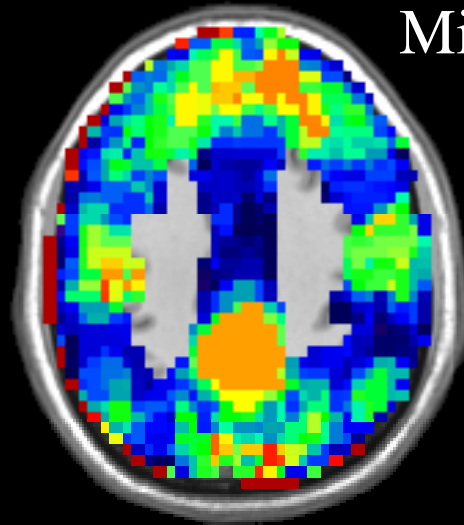
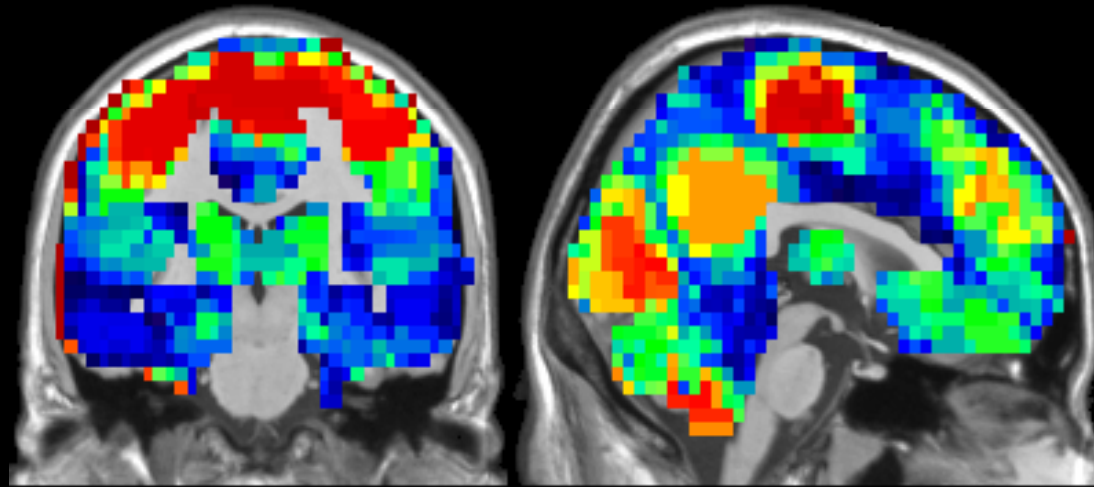
Brain Data



Across Subject Comparisons

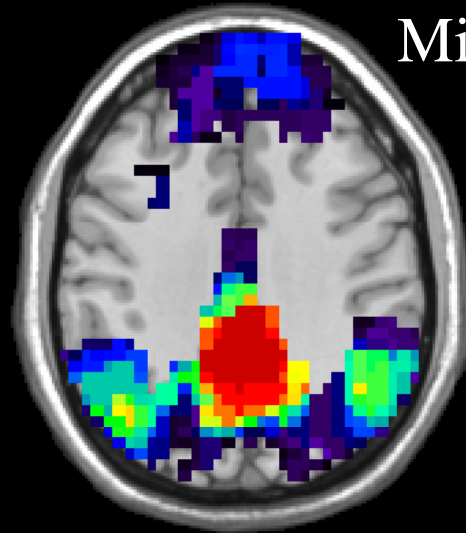
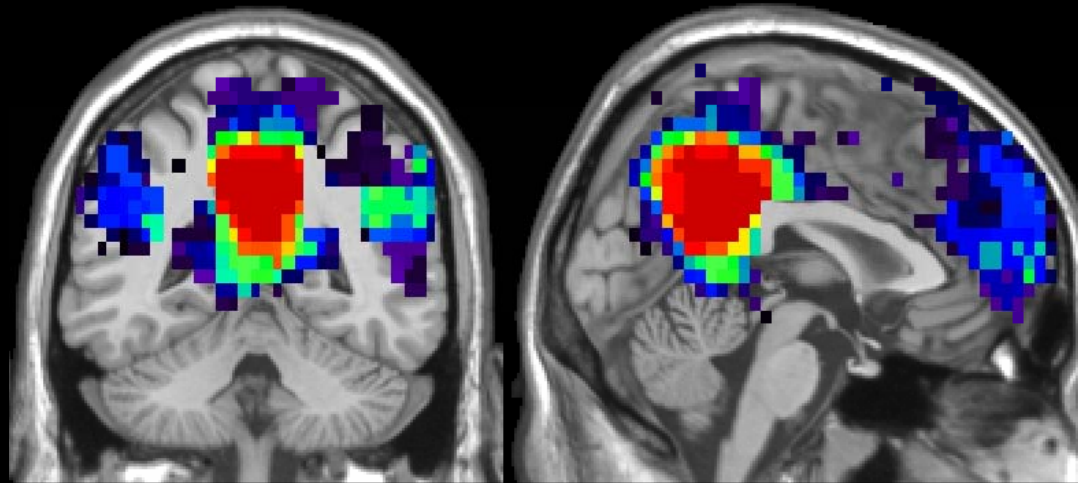


Group Scaled Inclusivity



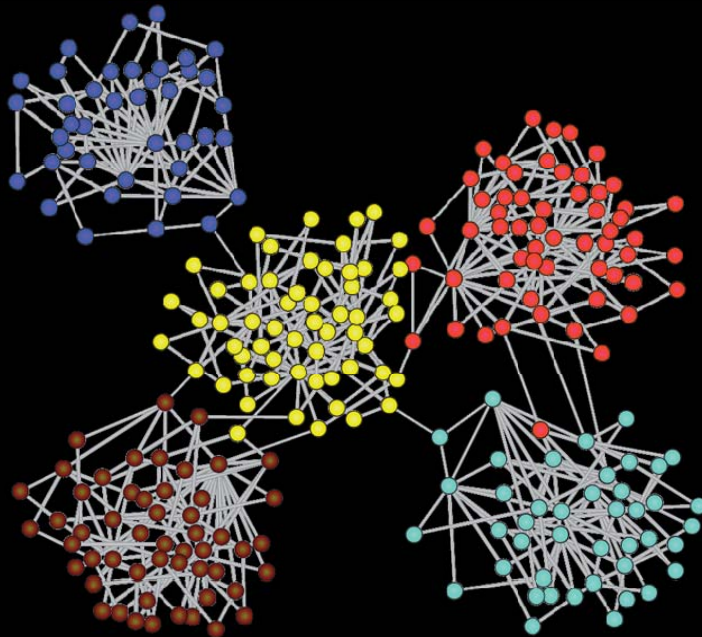
Min  Max
Scaled Inclusivity

Precuneus Neighborhood



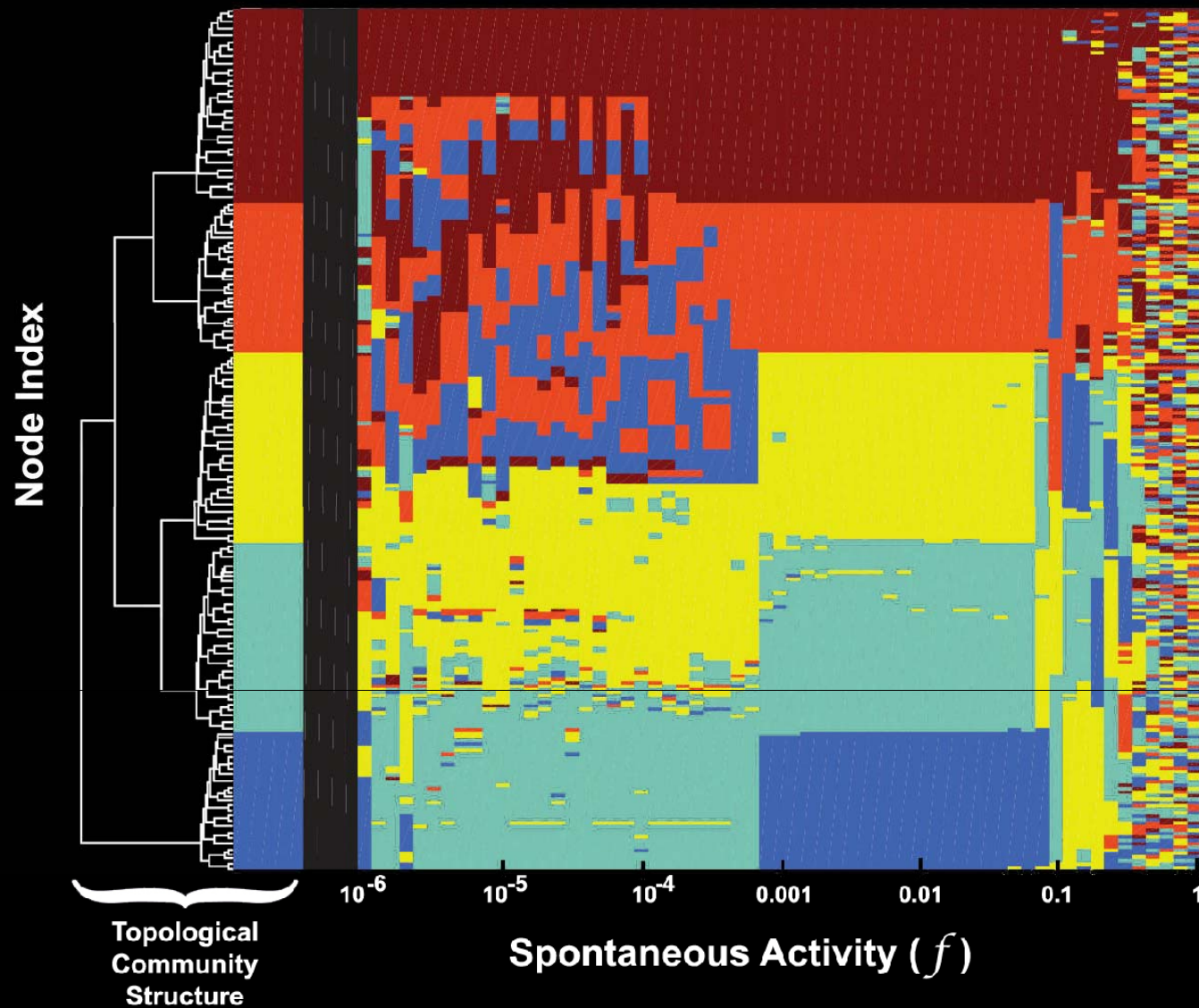
Min  Max
Scaled Inclusivity

Physiological Implications



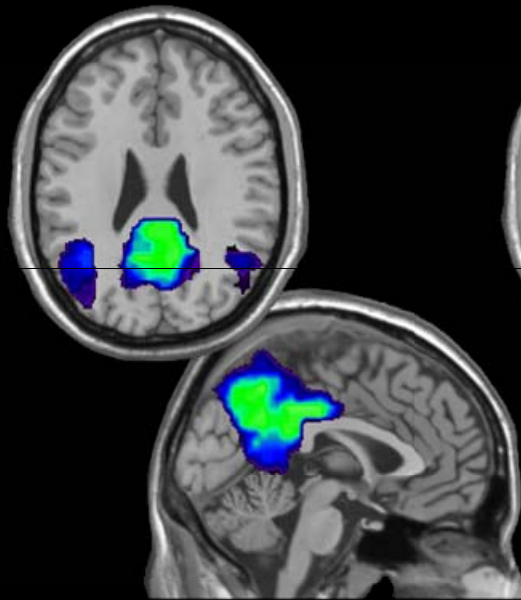
- Dynamic model
 - Susceptible
 - Excited
 - Refractory
- Vary spontaneous activity
- Compare -
 - Topological communities
 - Functional communities

Physiological Implications

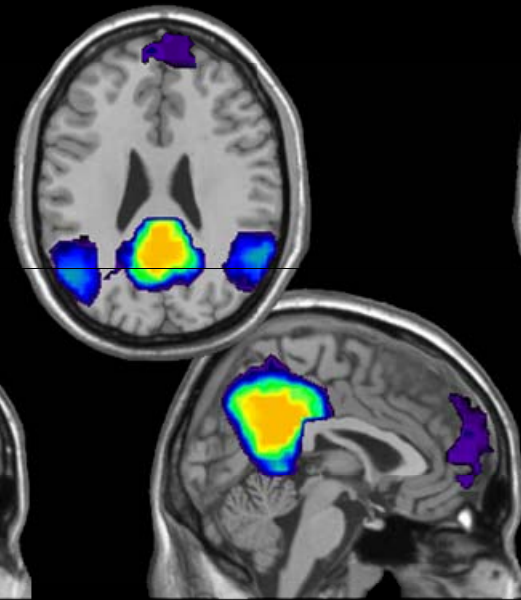


Physical Function in Older Adults

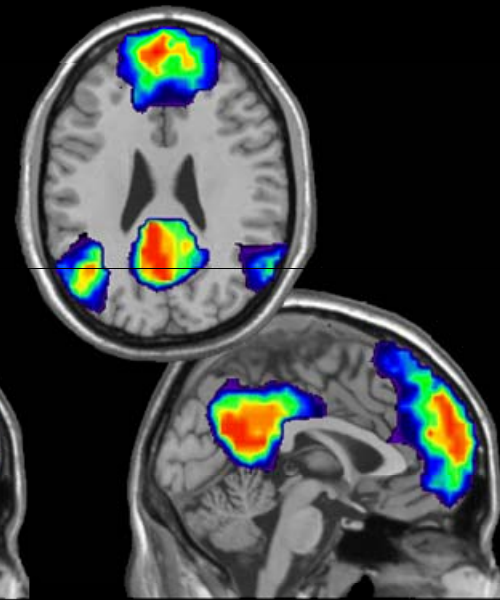
Low function



High function

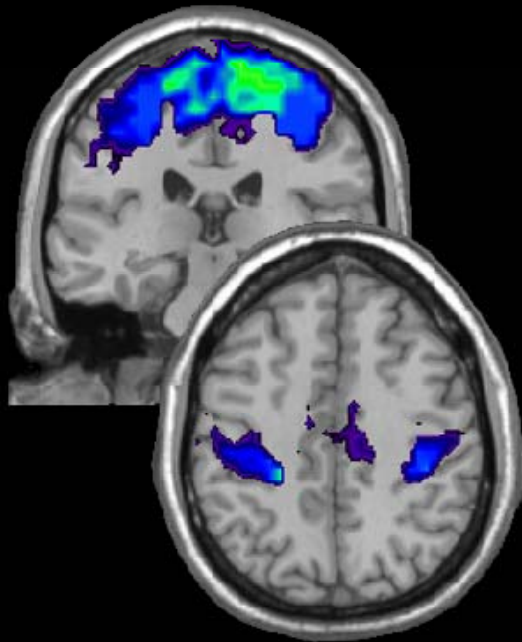


Young

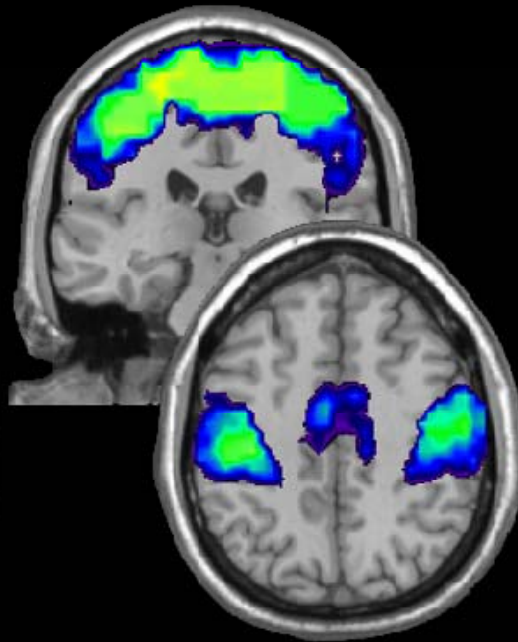


Physical Function in Older Adults

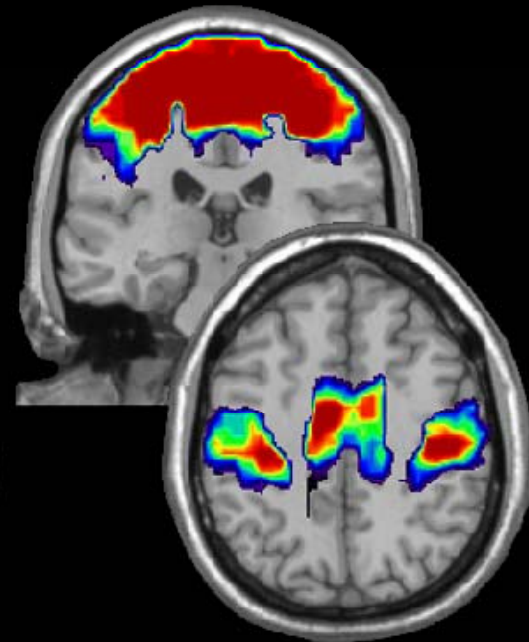
Low SPPB



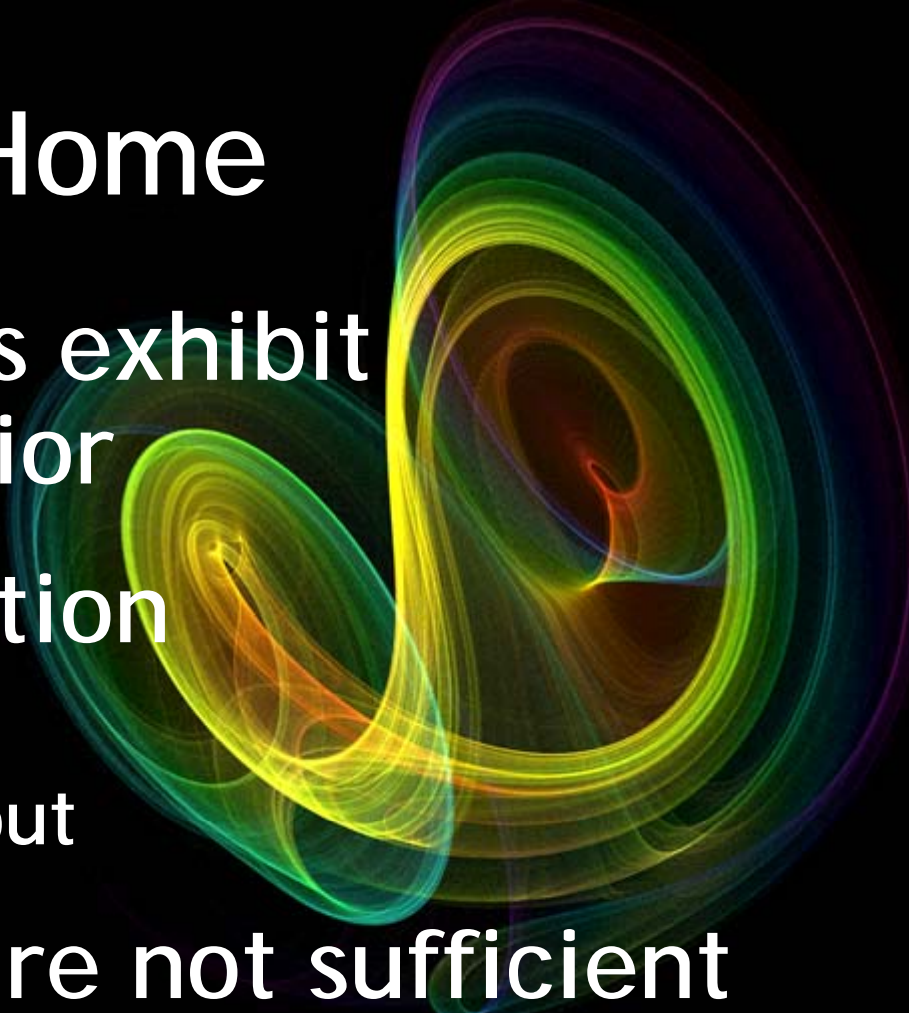
High SPPB

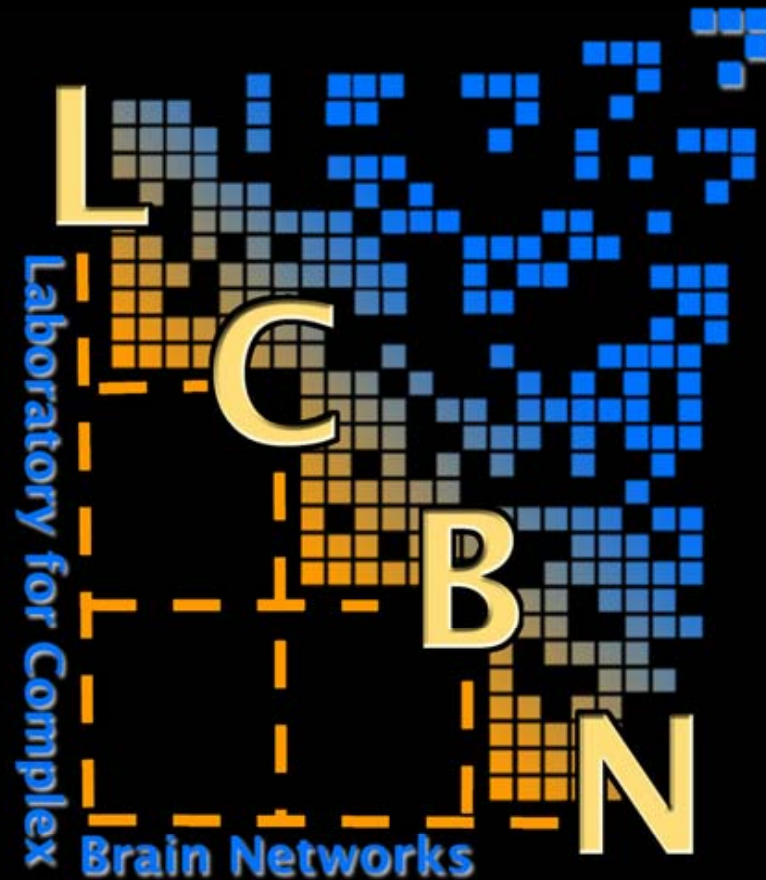


Young



Take Home

1. Complex systems exhibit emergent behavior
 2. Scientific revolution
 - a. Emergence is in
 - b. Reductionism is out
 3. Simple metrics are not sufficient
 4. Community structure - a step in the right direction
- 
- An abstract, colorful fractal pattern consisting of overlapping, swirling lines in shades of green, yellow, orange, and blue, set against a black background. The pattern is complex and organic, resembling a stylized figure or a series of interconnected loops.



Paul J. Laurienti, MD, PhD