

A profile photograph of a person's head, facing right. Overlaid on the head is a complex network of colored dots (red, blue, green, yellow) connected by thin lines, representing functional brain networks.

Measuring human functional brain networks

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grattonlab.org

Acknowledgments

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*** Recruiting for lab @ Florida State ***



Funding



National Institute
of Mental Health

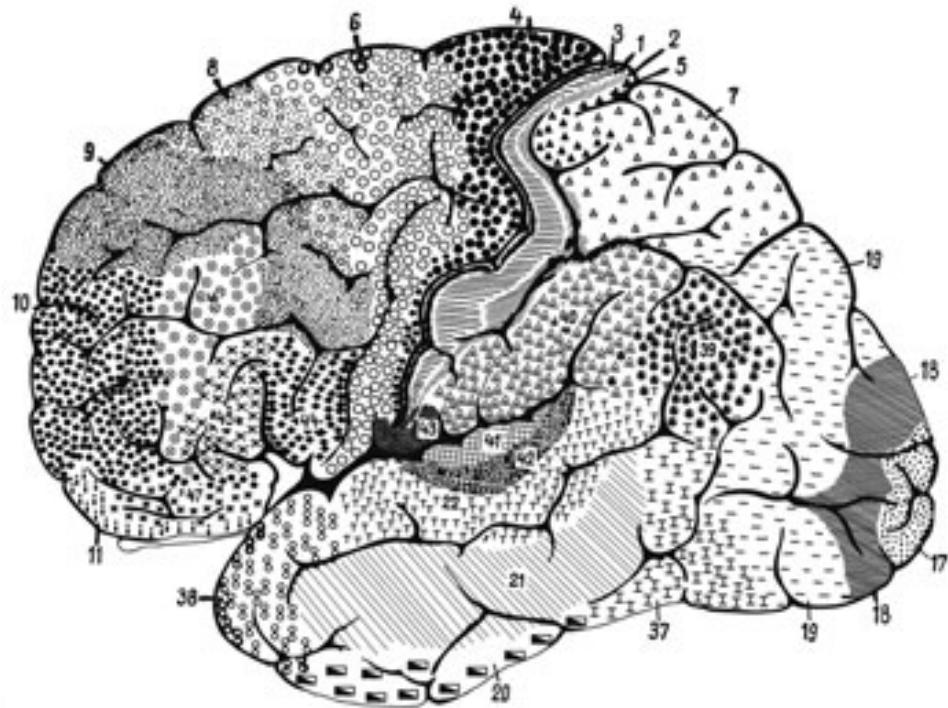


National Institute
on Aging



Two viewpoints on cognition & brain function

specialized processing



coordinated interactions



Talk Outline

1. Background: functional connectivity
2. Recent work: Individual 'precision' brain networks
3. Tutorial

Open up tutorial by either :

1. Logging in and running it on the JupyterHub:

<https://neurohackademy.2i2c.cloud/>

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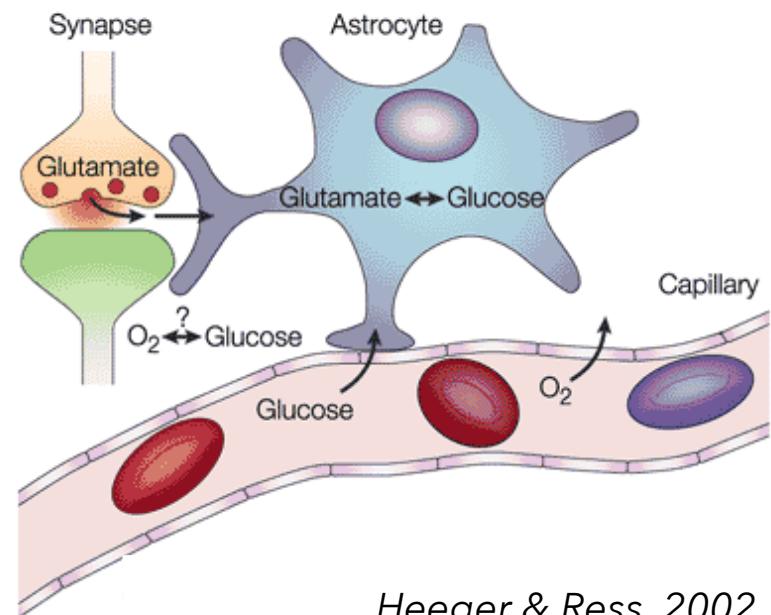
Talk Outline

- 1. Background: functional connectivity**
2. Recent work: Individual 'precision' brain networks
3. Tutorial

functional Magnetic Resonance Imaging (fMRI)



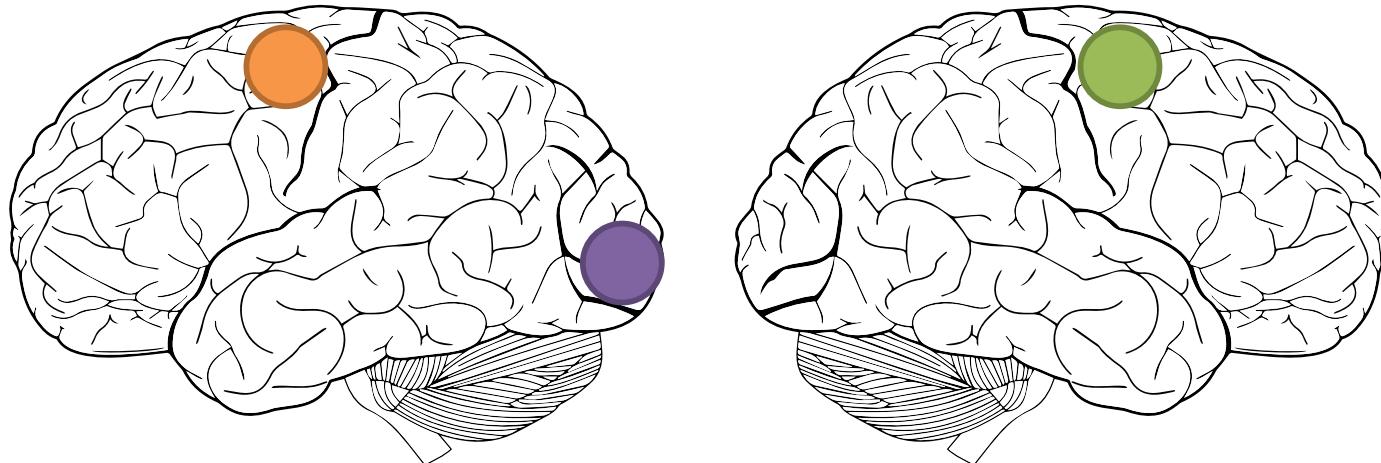
Blood Oxygen Level Dependent (BOLD) Signal



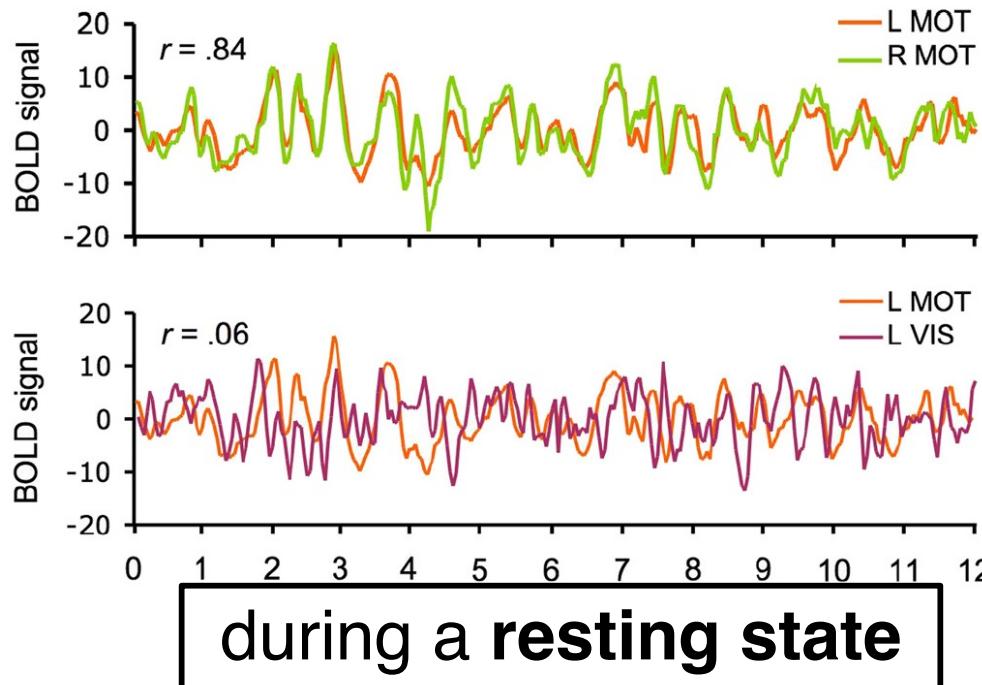
Heeger & Ress, 2002

- EEG/MEG
- ECoG
- Optical signals
- Single/multi-unit electrode recordings

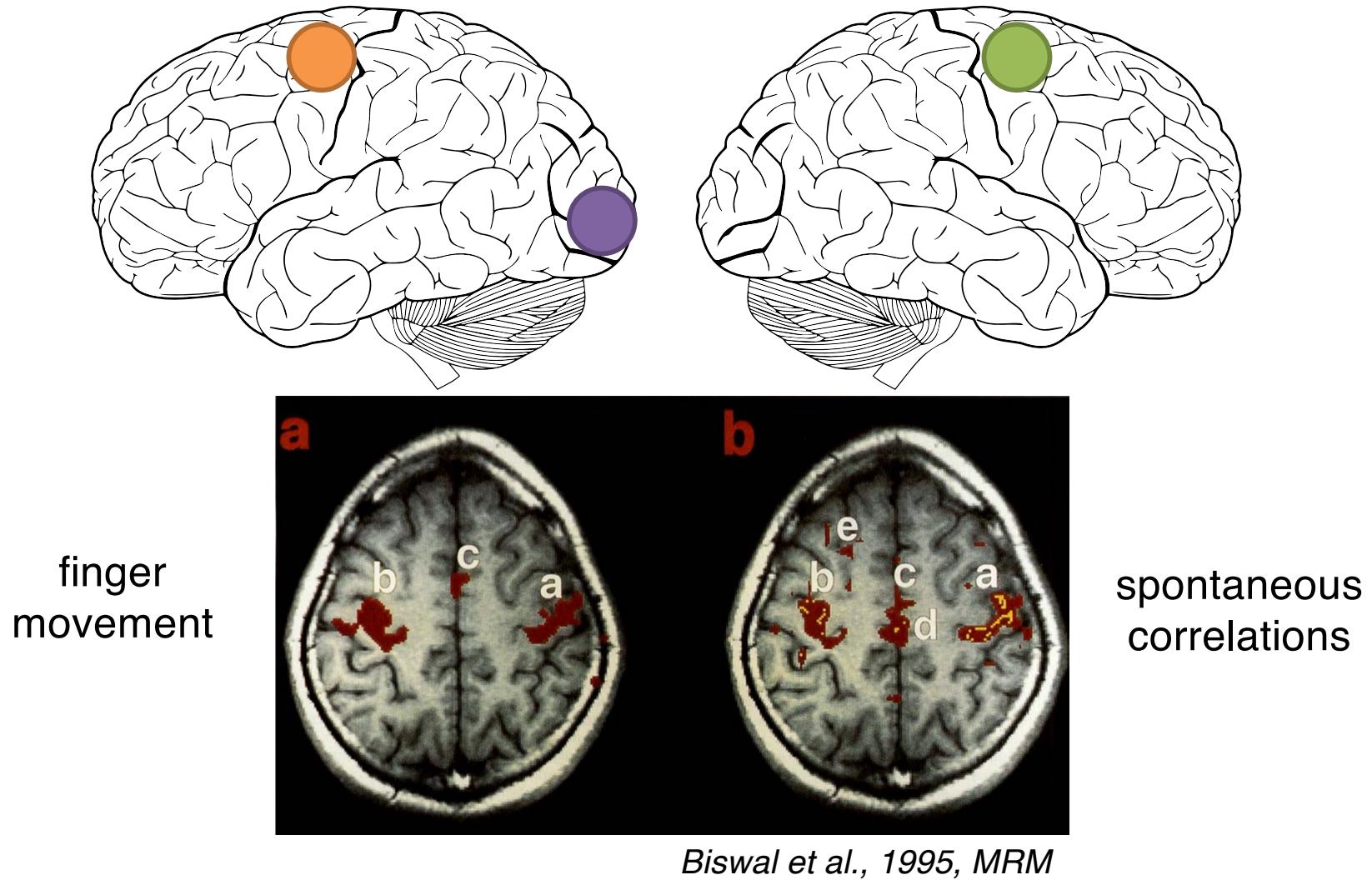
Functional Connectivity (FC): measuring relationships across brain regions



- correlation
- coherence
- PCA
- ICA
- etc.

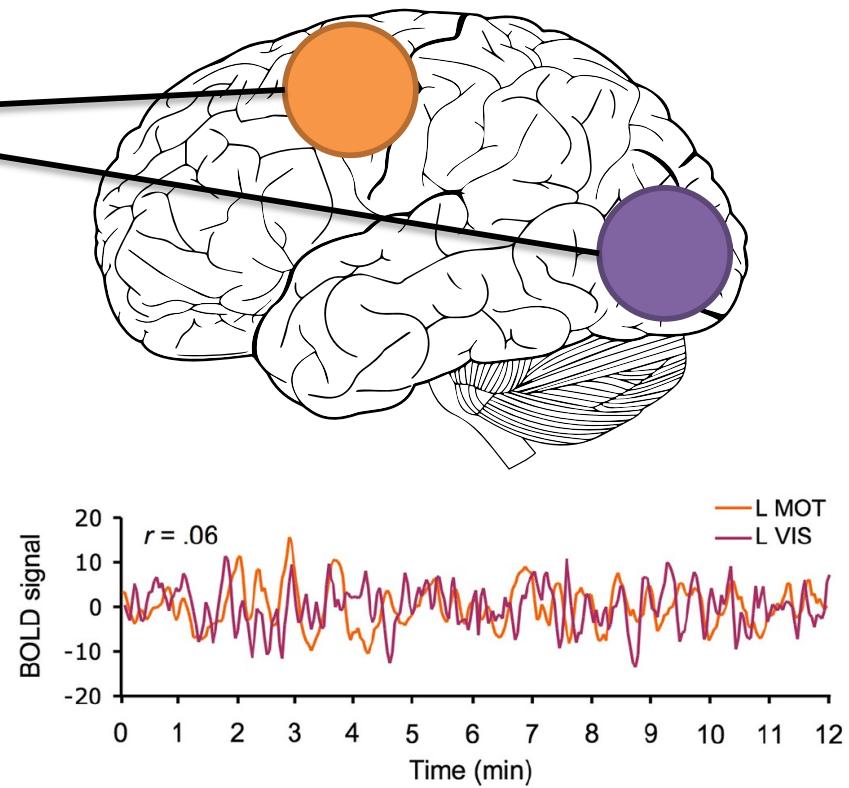
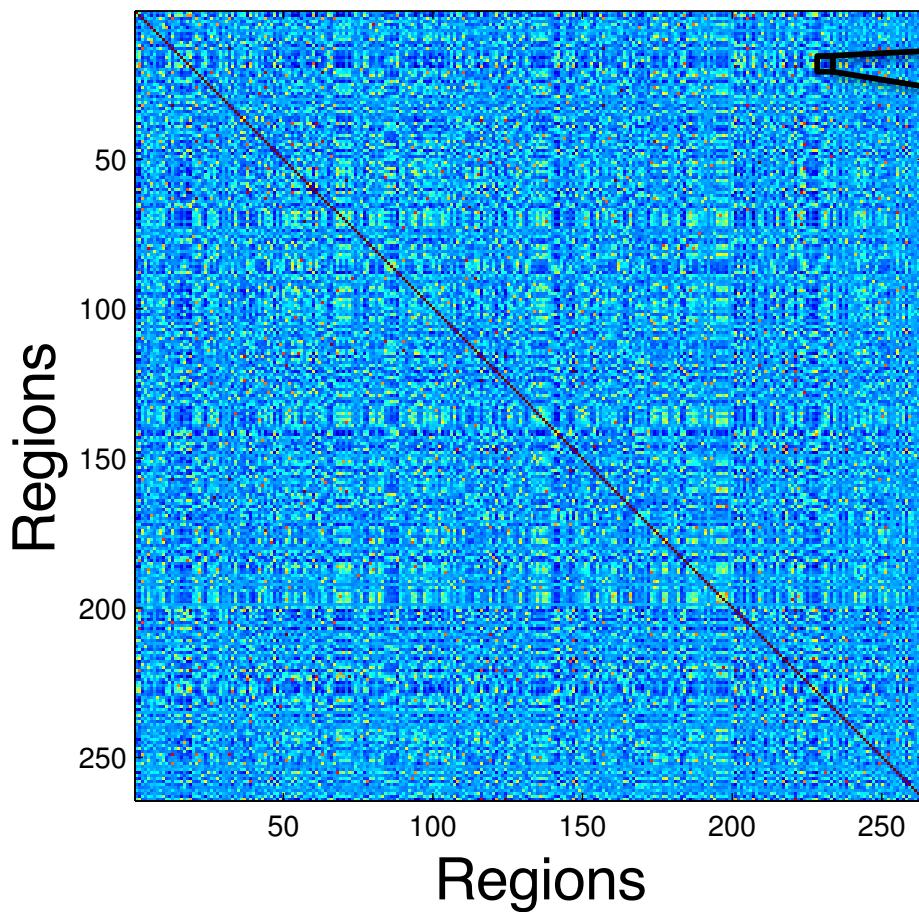


Functional Connectivity (FC): measuring relationships across brain regions



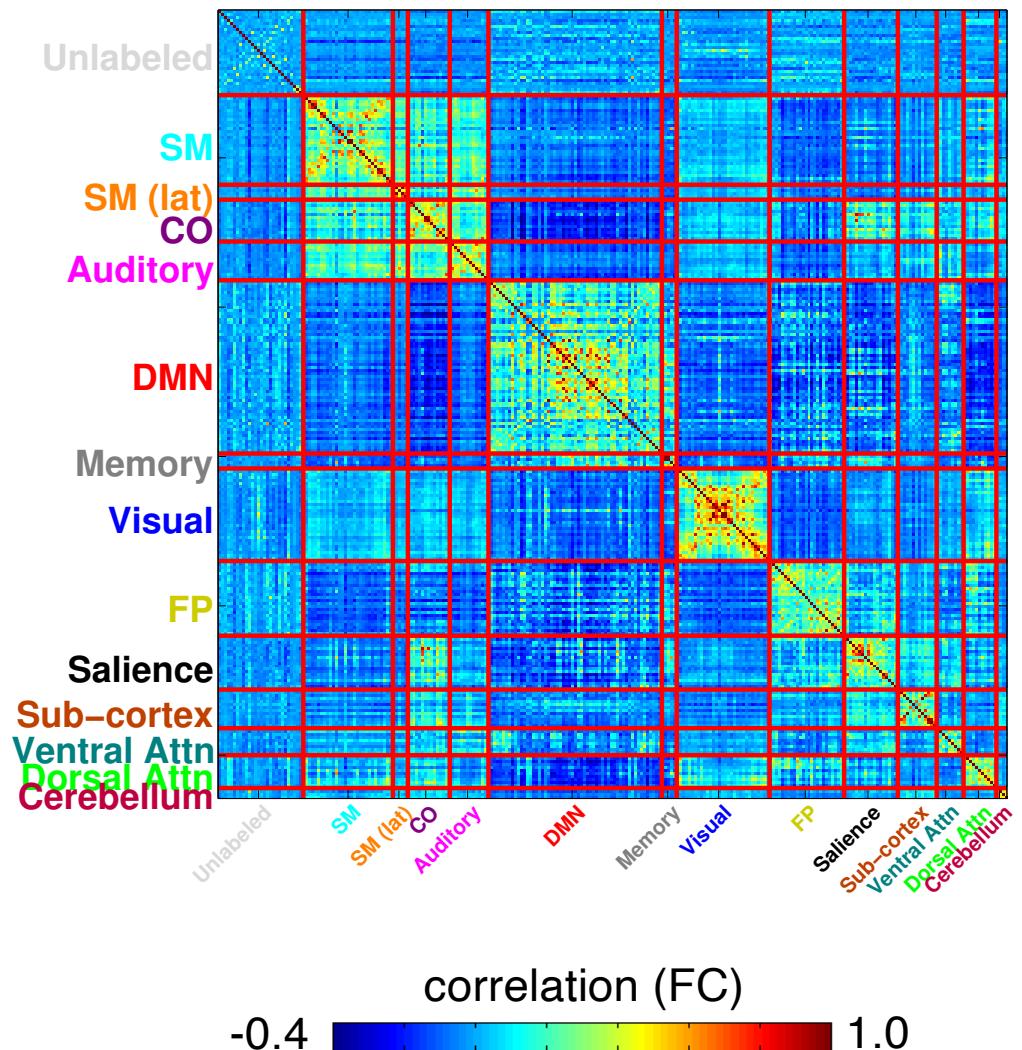
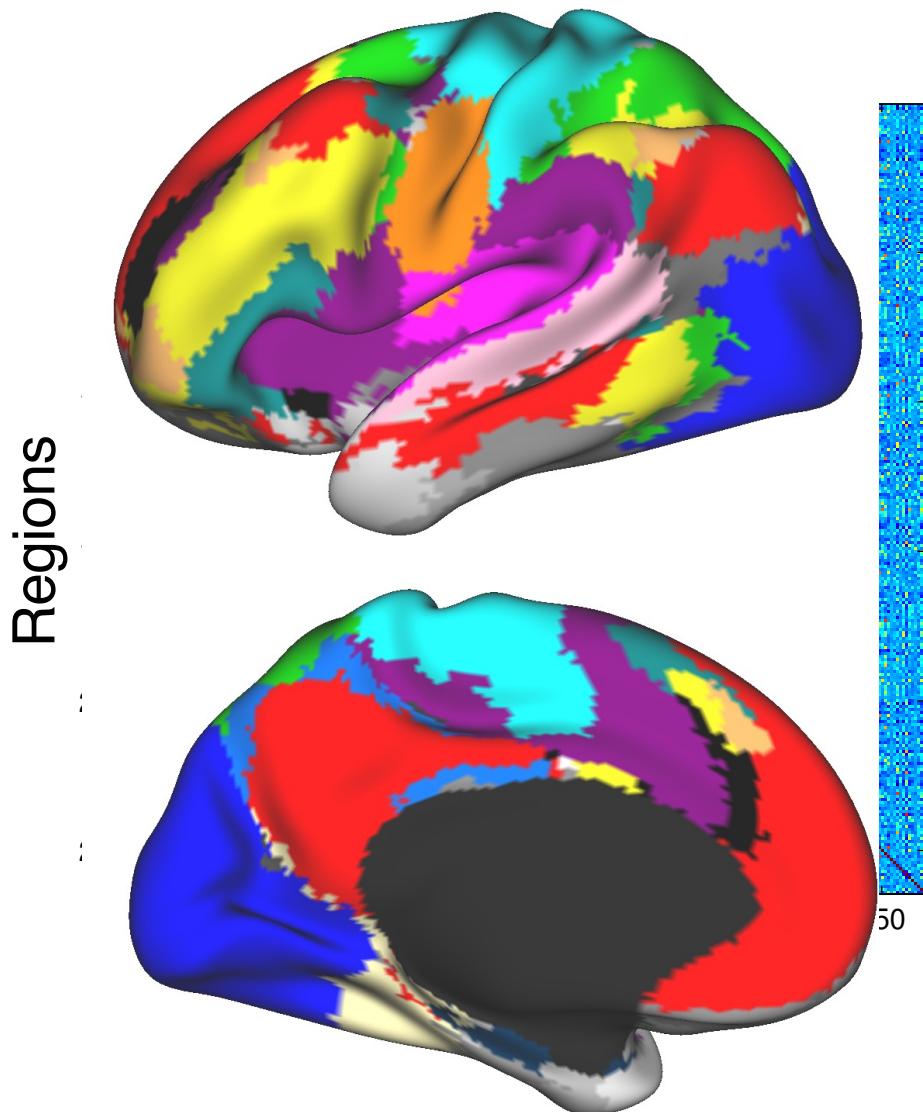
during a **resting state**

FC: A way to map brain organization



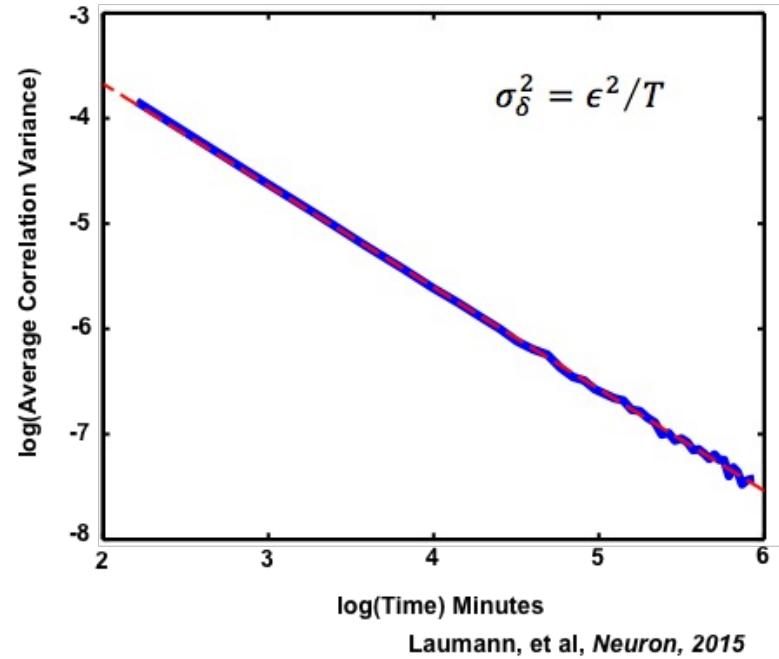
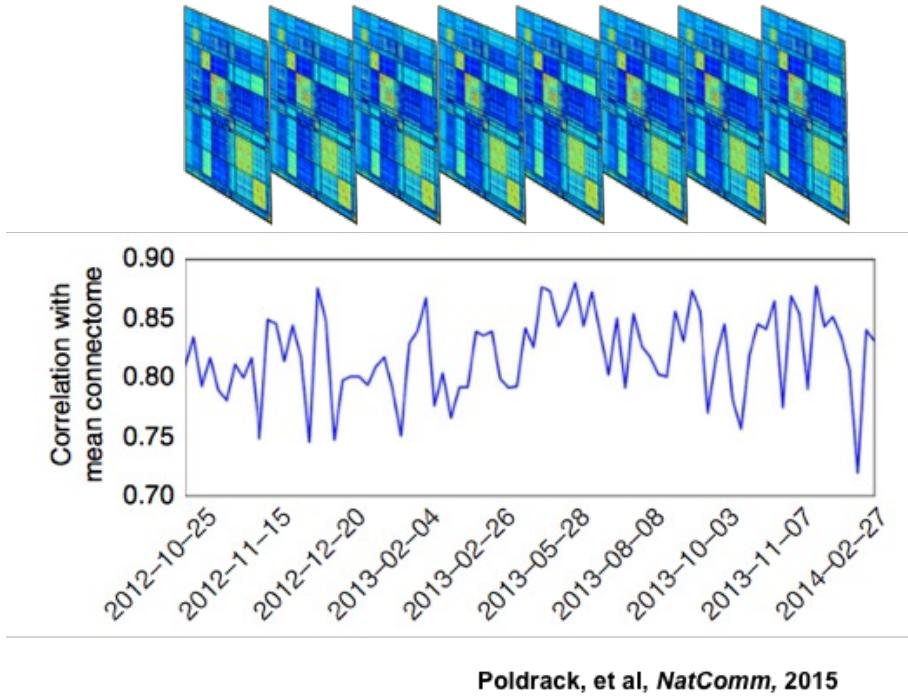
correlation (FC)
-0.4 1.0

FC: A way to map brain organization



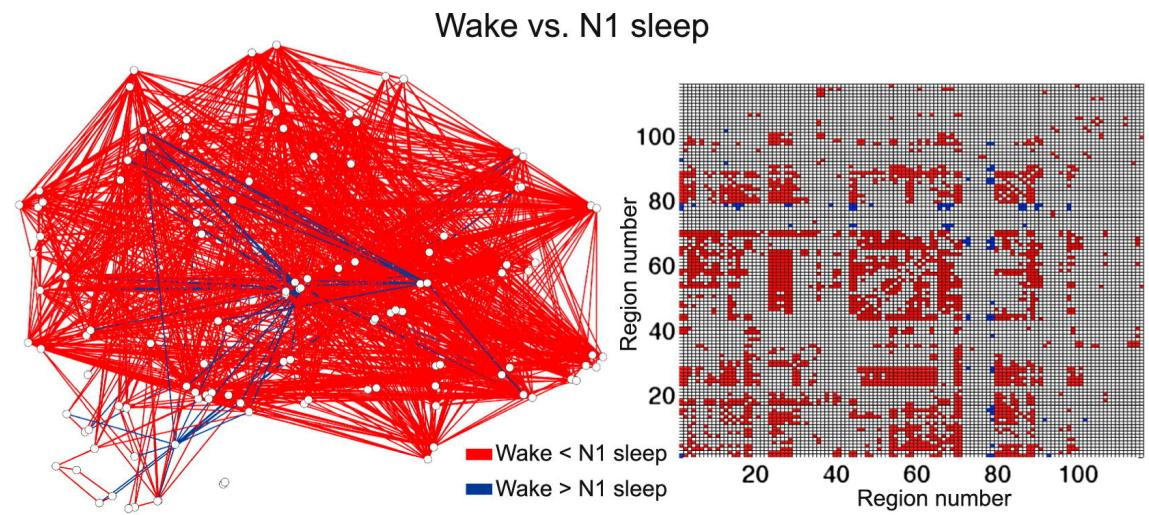
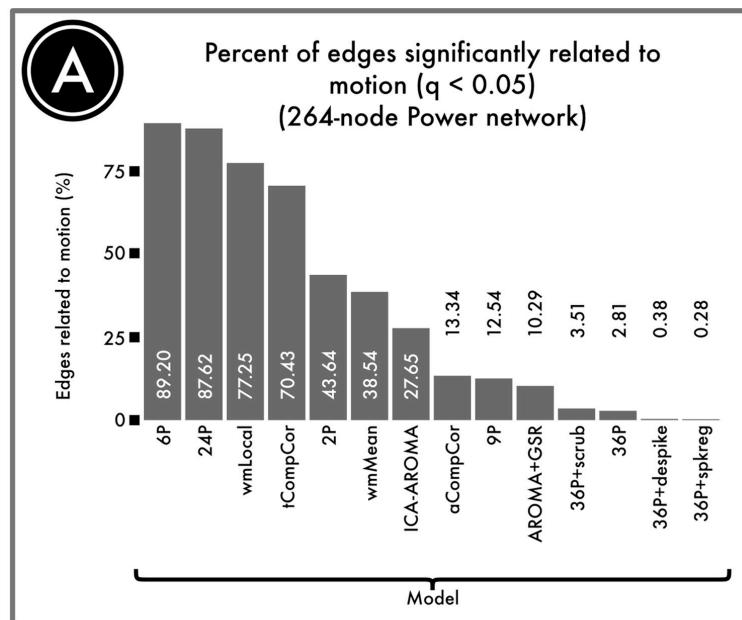
FC: cautionary notes

- Unlike task-based modulations, there is no external imposed perturbation
- Need to exert additional caution about intrinsic variability and other sources of noise
 - Sampling variability



FC: cautionary notes

- Unlike task-based modulations, there is no external imposed perturbation
 - Need to exert additional caution about intrinsic variability and other sources of noise
 - Sampling variability
 - Motion & respiration
 - Arousal (?)



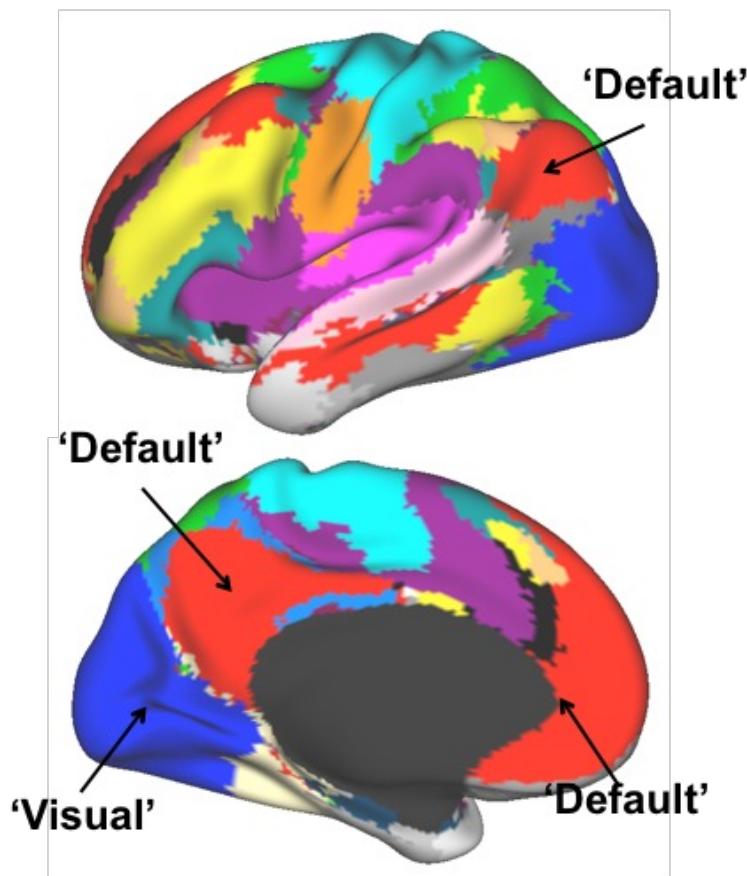
Tagliazucchi et al., 2014

Ciric et al., 2016

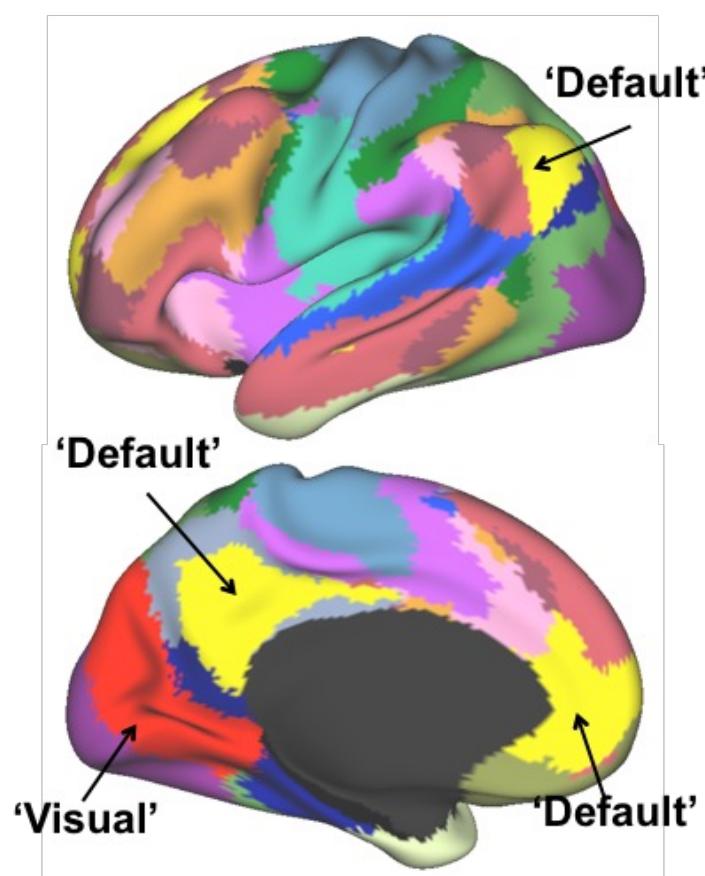
See also: Parkes et al., 2018; Power et al., 2017

FC: A way to map brain organization

WUSTL



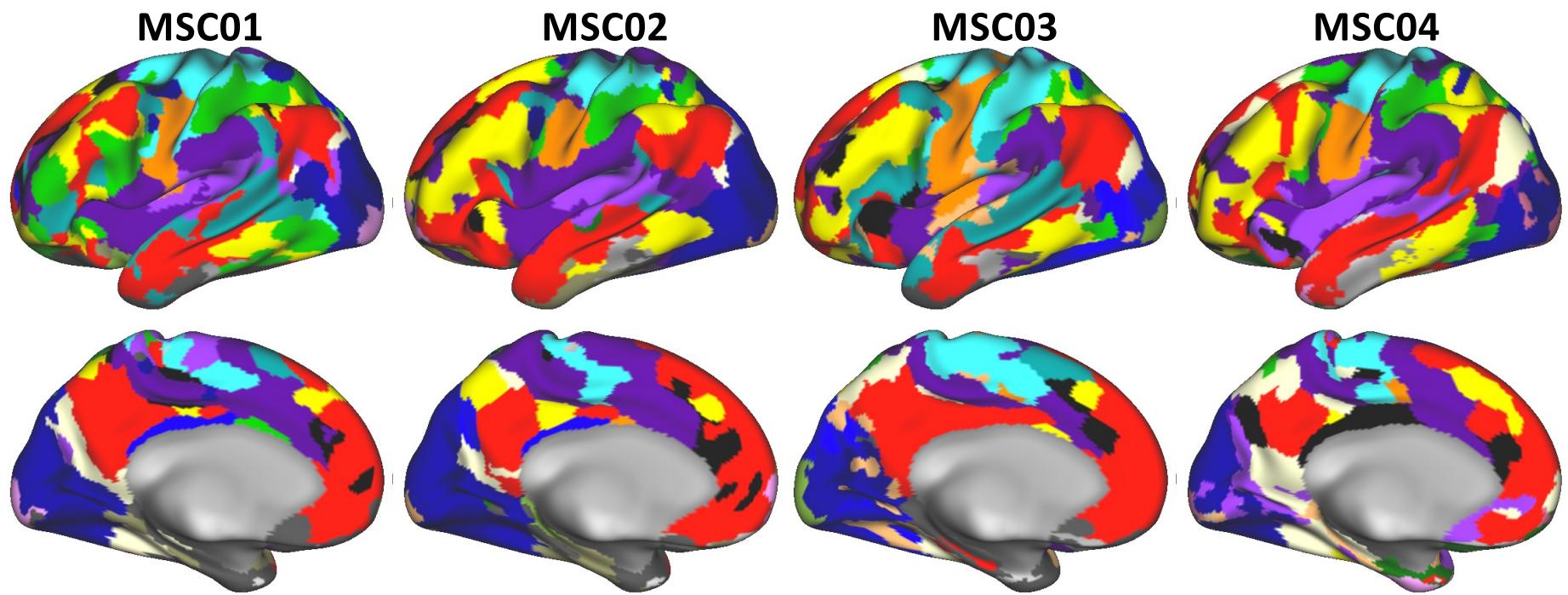
Harvard



Power et al., 2011, Neuron

Yeo et al., 2011, J Neurophys

Functional brain networks in individuals



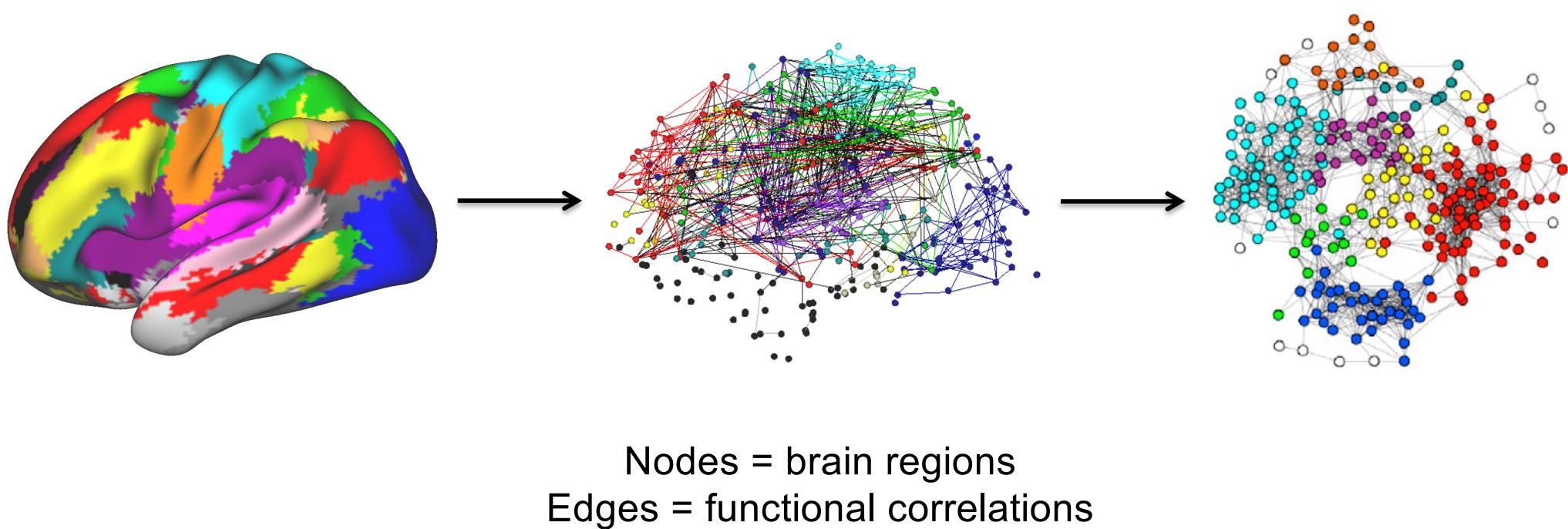
Gordon et al., 2017, Neuron

Braga et al., 2017, Neuron

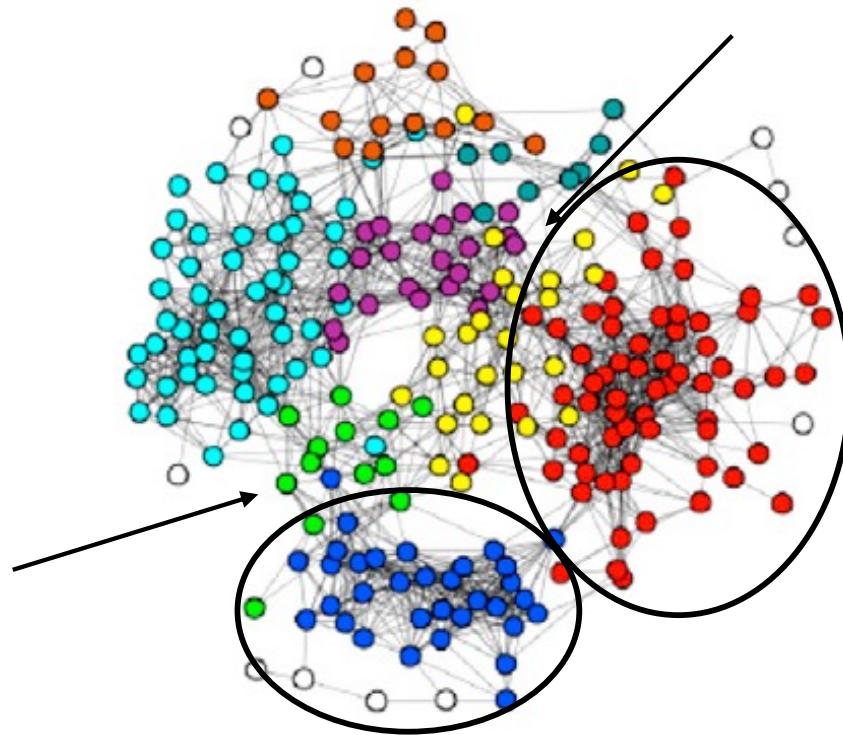
Laumann et al., 2015, Neuron

Poldrack et al., 2015, Nat Commun

FC: From specialized regions to a complex system

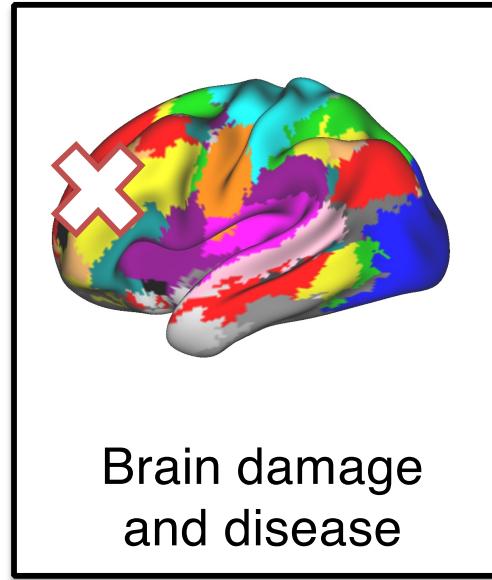
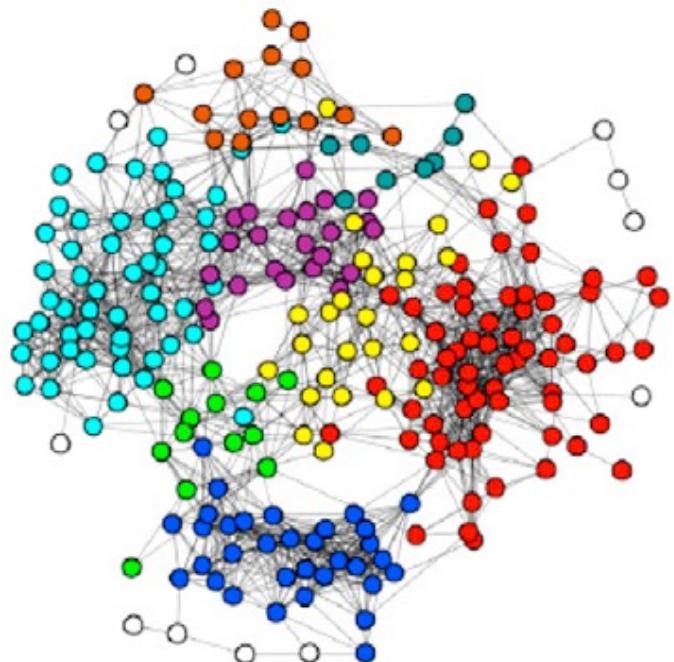
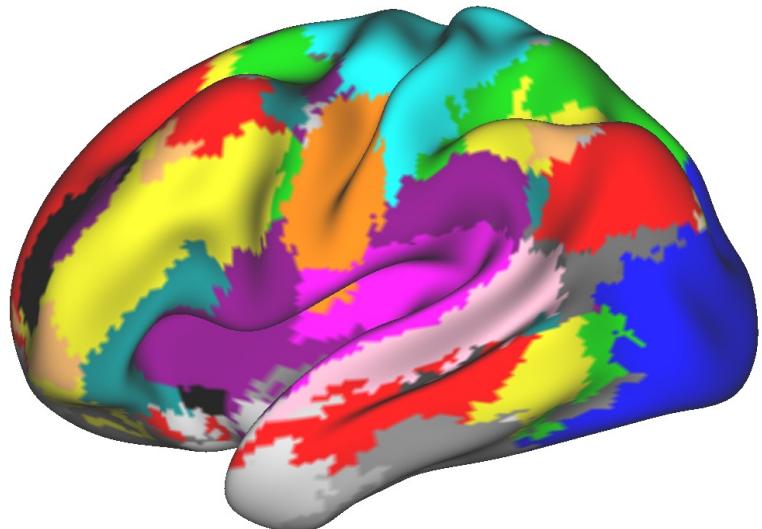


FC: From specialized regions to a complex system

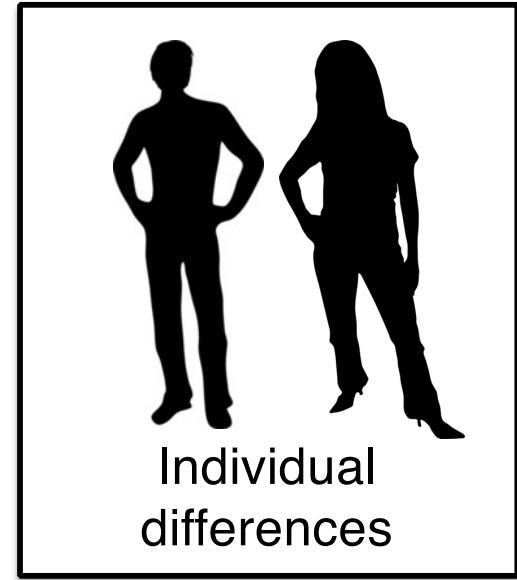


1. Quantify properties of the graph as a whole (e.g., **network organization**)
2. Quantify properties of individual nodes (e.g., **hubs**)

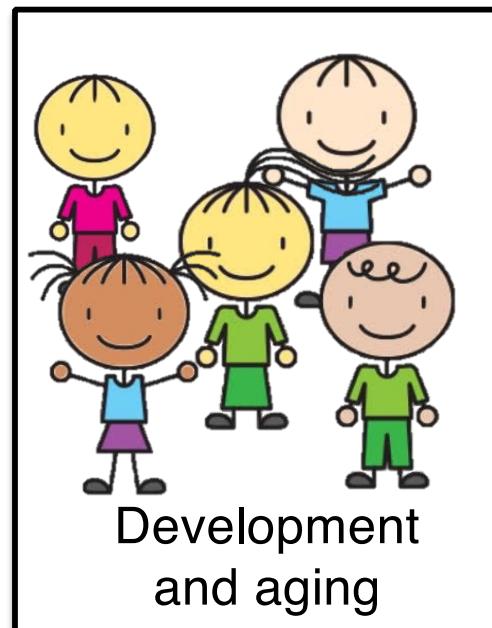
The Promise of Functional Connectivity



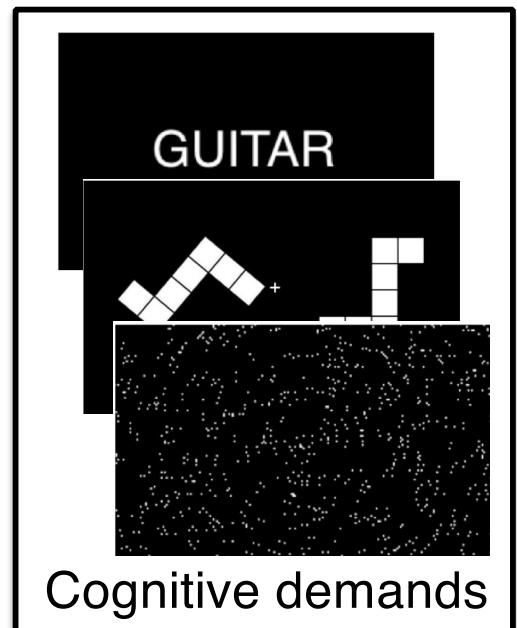
Brain damage
and disease



Individual
differences



Development
and aging

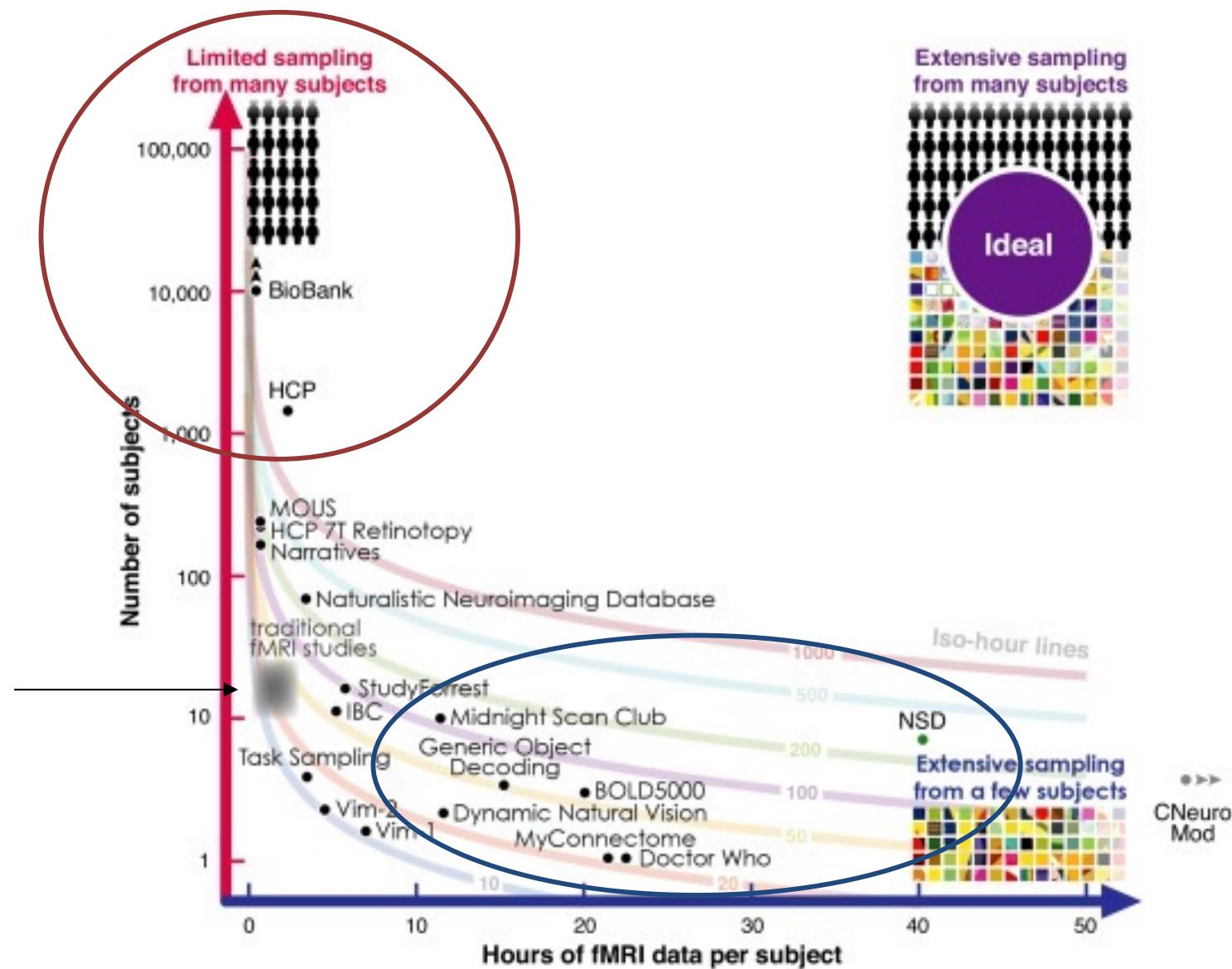


Cognitive demands

Talk Outline

1. Background: functional connectivity
2. **Recent work: Individual 'precision' brain networks**
3. Tutorial

Sampling paradigms in functional connectivity



Precision fMRI Datasets



My Connectome



1 subject
x 80+ rs-fMRI sessions
+ surveys, blood draws, etc.

Poldrack et al., 2015, *Nat Comm*

Midnight Scan Club



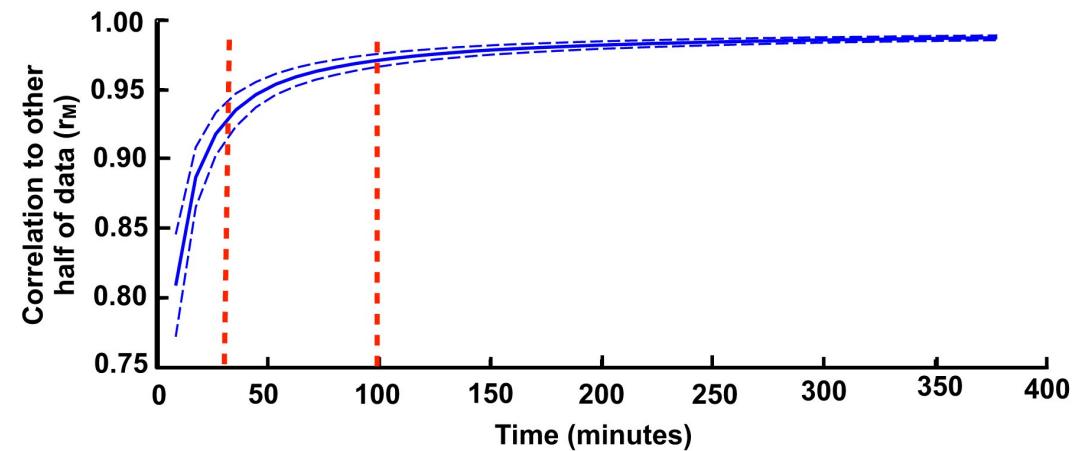
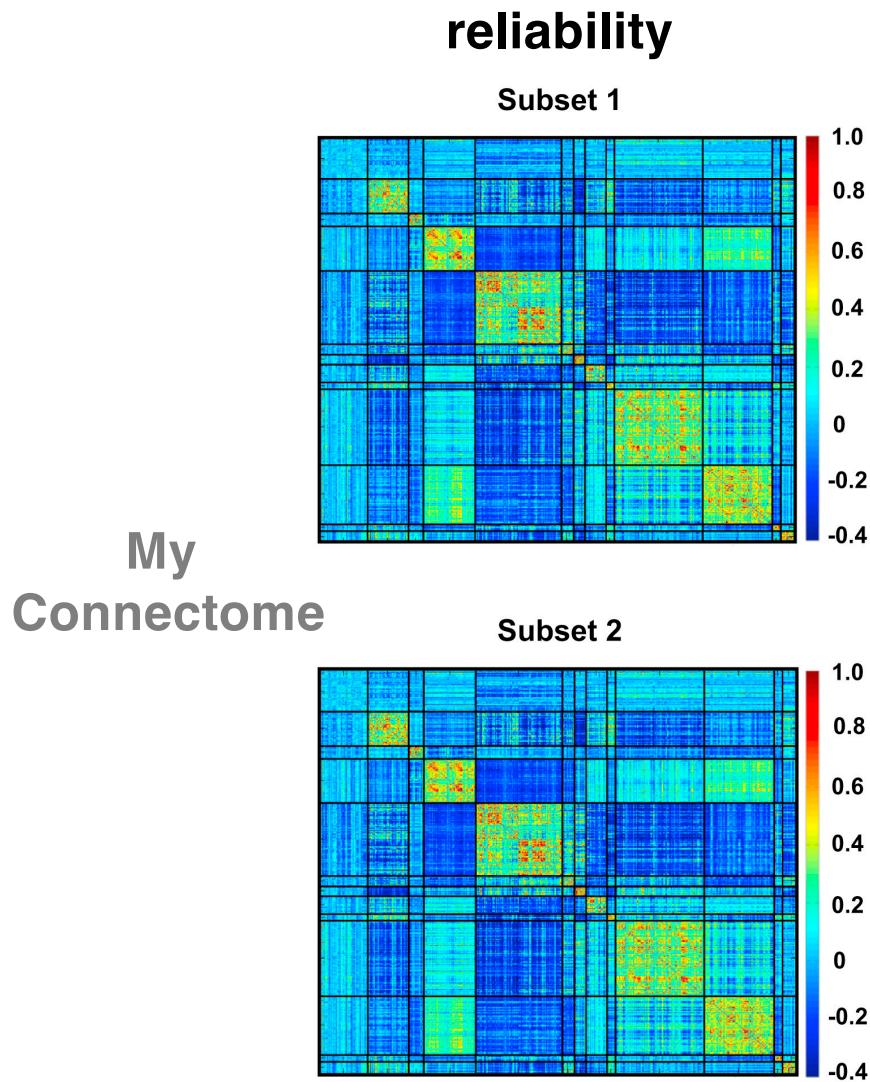
10 subjects
x 10 fMRI sessions
x 4 tasks + rest

Gordon et al., 2017, *Neuron*



What can you do with precision fMRI?

1. Improve measurement of brain networks

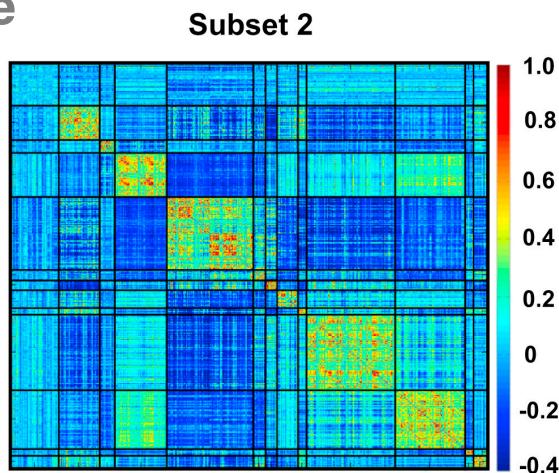
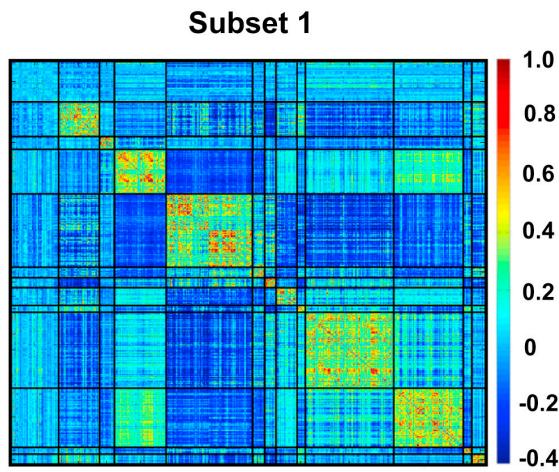


Laumann et al., 2015, *Neuron*

What can you do with precision fMRI?

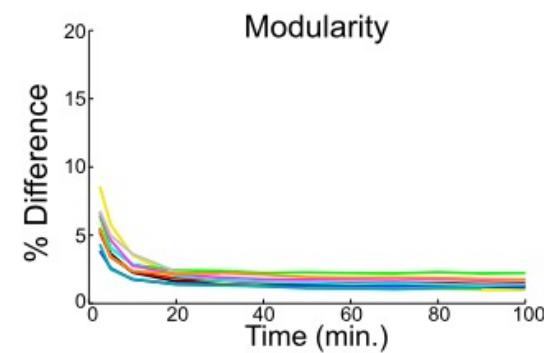
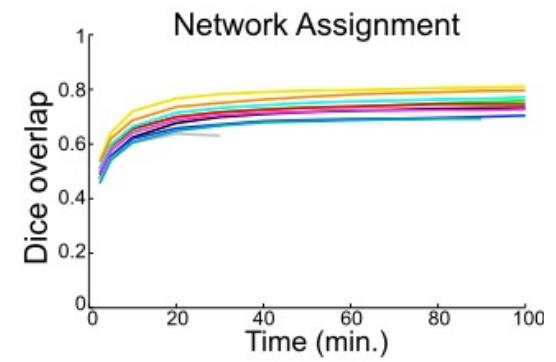
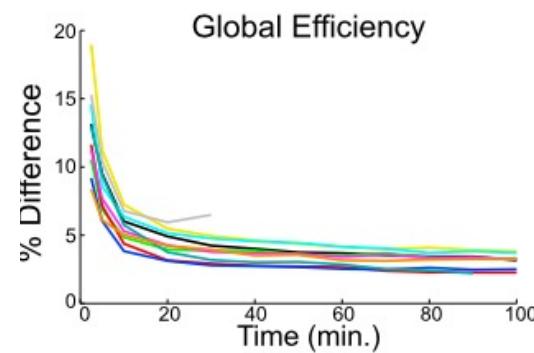
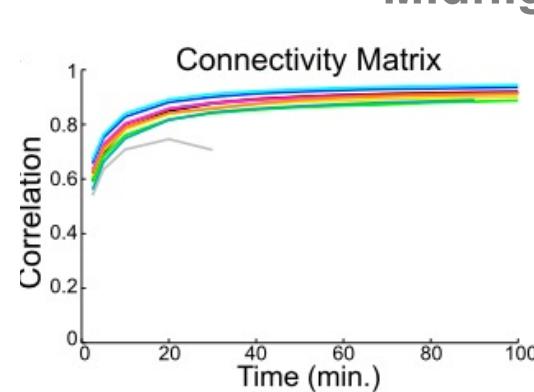
1. Improve measurement of brain networks

reliability



My
Connectome

Midnight Scan Club



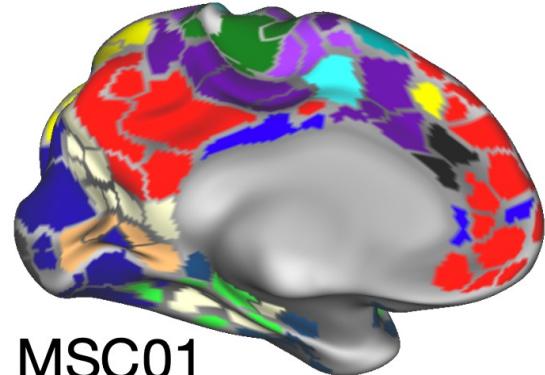
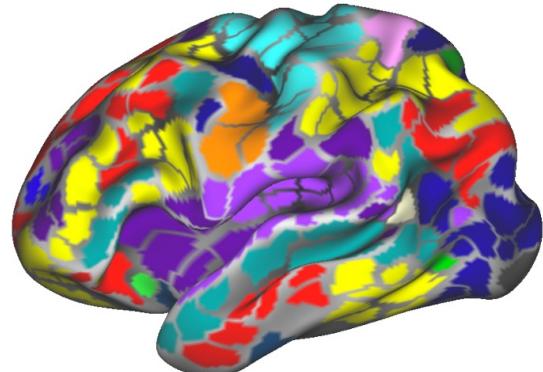
Gordon et al., 2016, *Neuron*

Laumann et al., 2015, *Neuron*

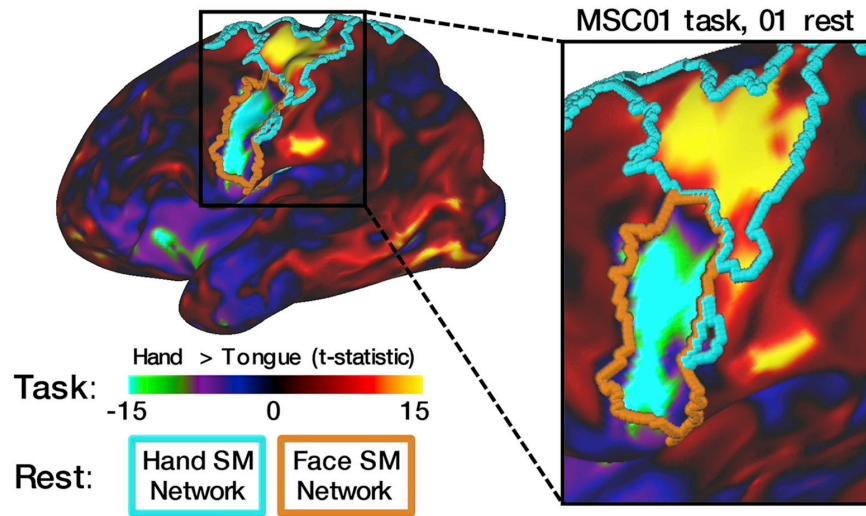
What can you do with precision fMRI?

1. Improve measurement of brain networks

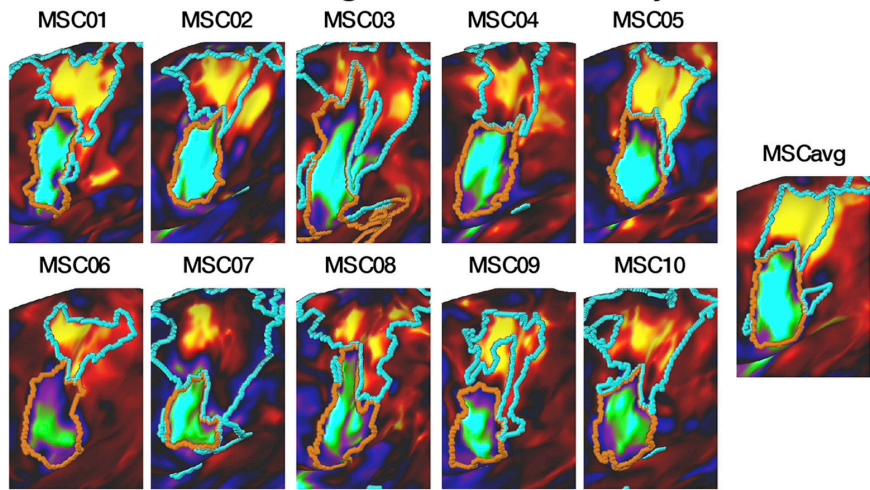
validity



Gordon et al., 2017, *Neuron*



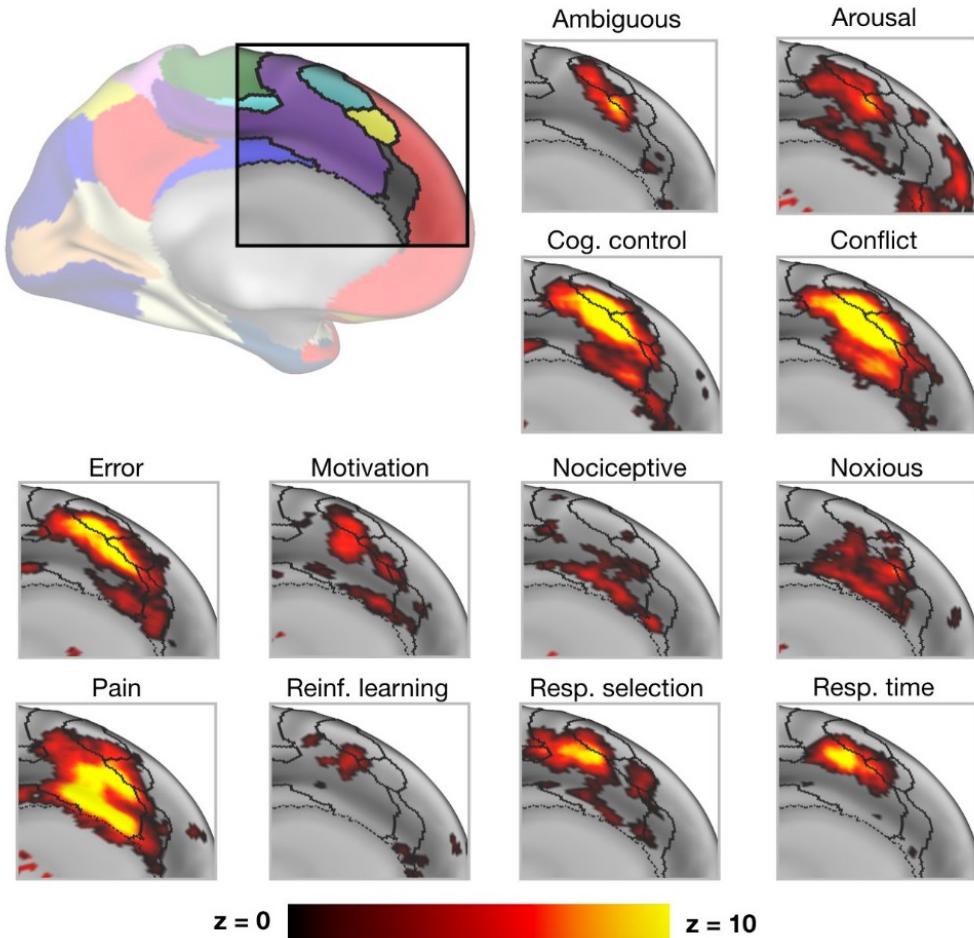
Task/rest alignment within subjects



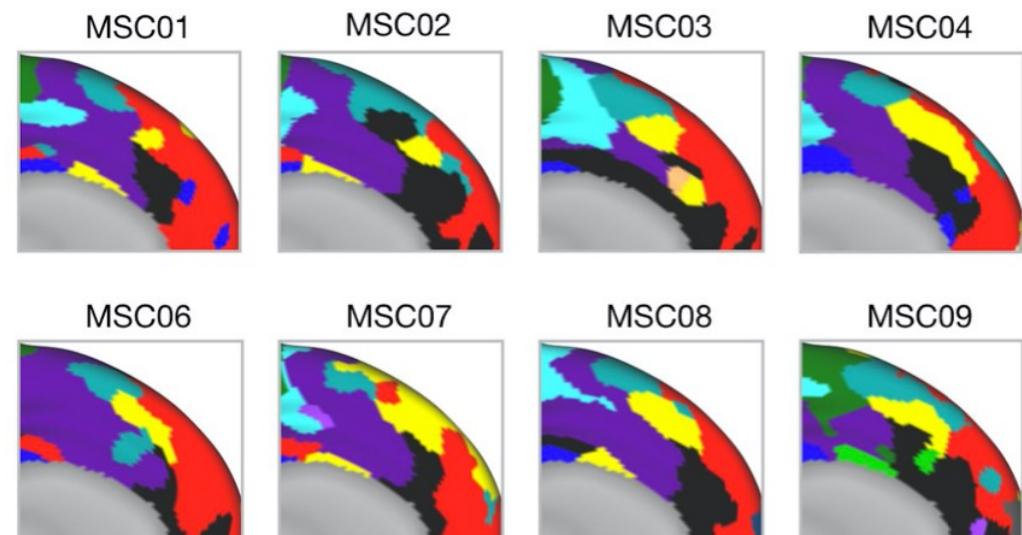
What can you do with precision fMRI?

1. Improve measurement of brain networks

Neurosynth



MSC: individual networks



Derek Smith



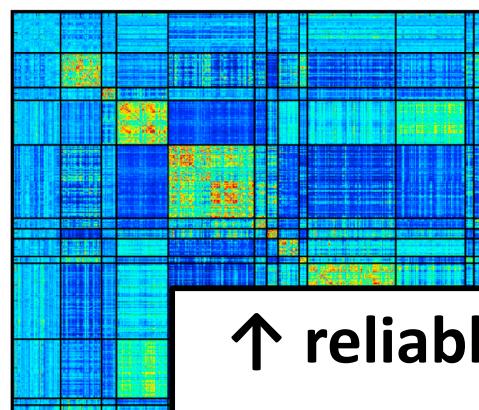
Smith et al., 2021, *Curr Op in Beh Sciences*

What can you do with precision fMRI?

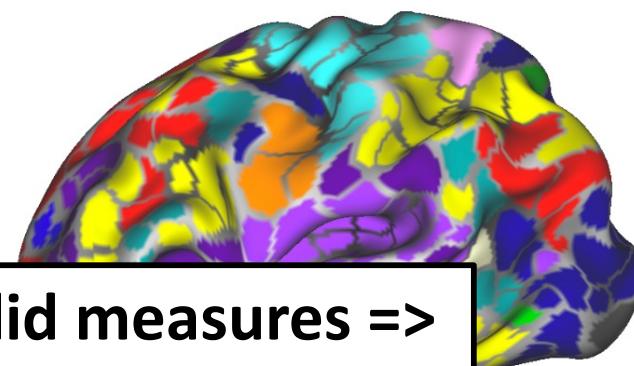
1. Improve measurement of brain networks

reliability

Subset 1



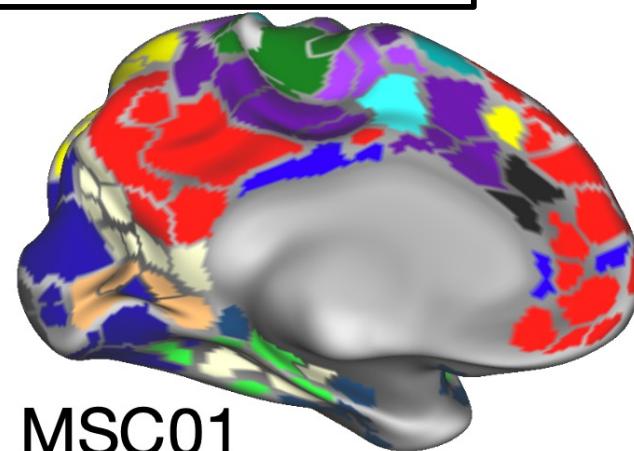
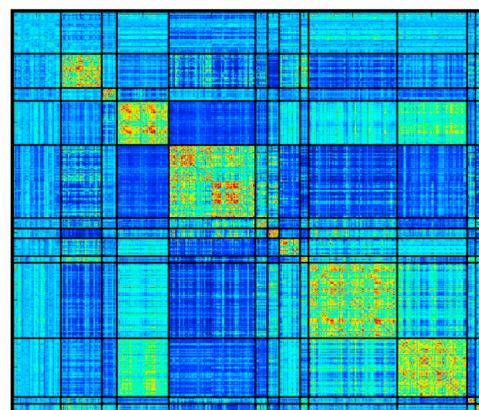
validity



↑ reliable and valid measures =>

↑ prediction

Subset 2

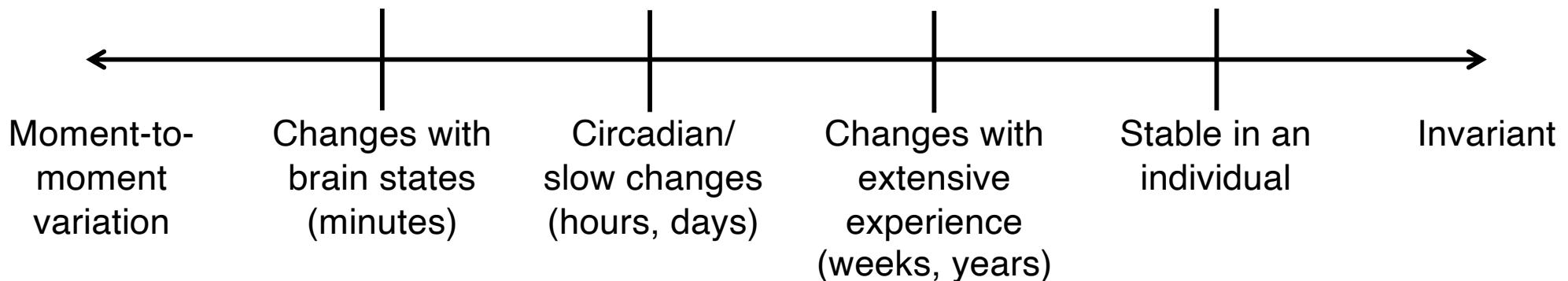


MSC01

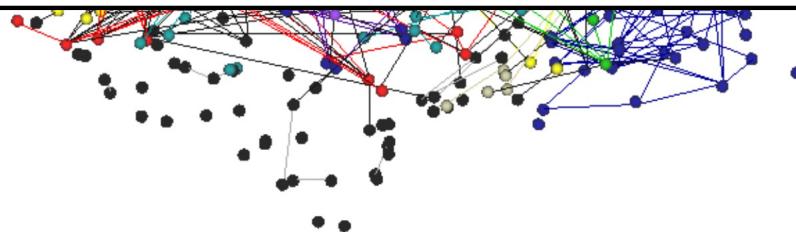
What can you do with precision fMRI?

2. Study basic properties of functional networks

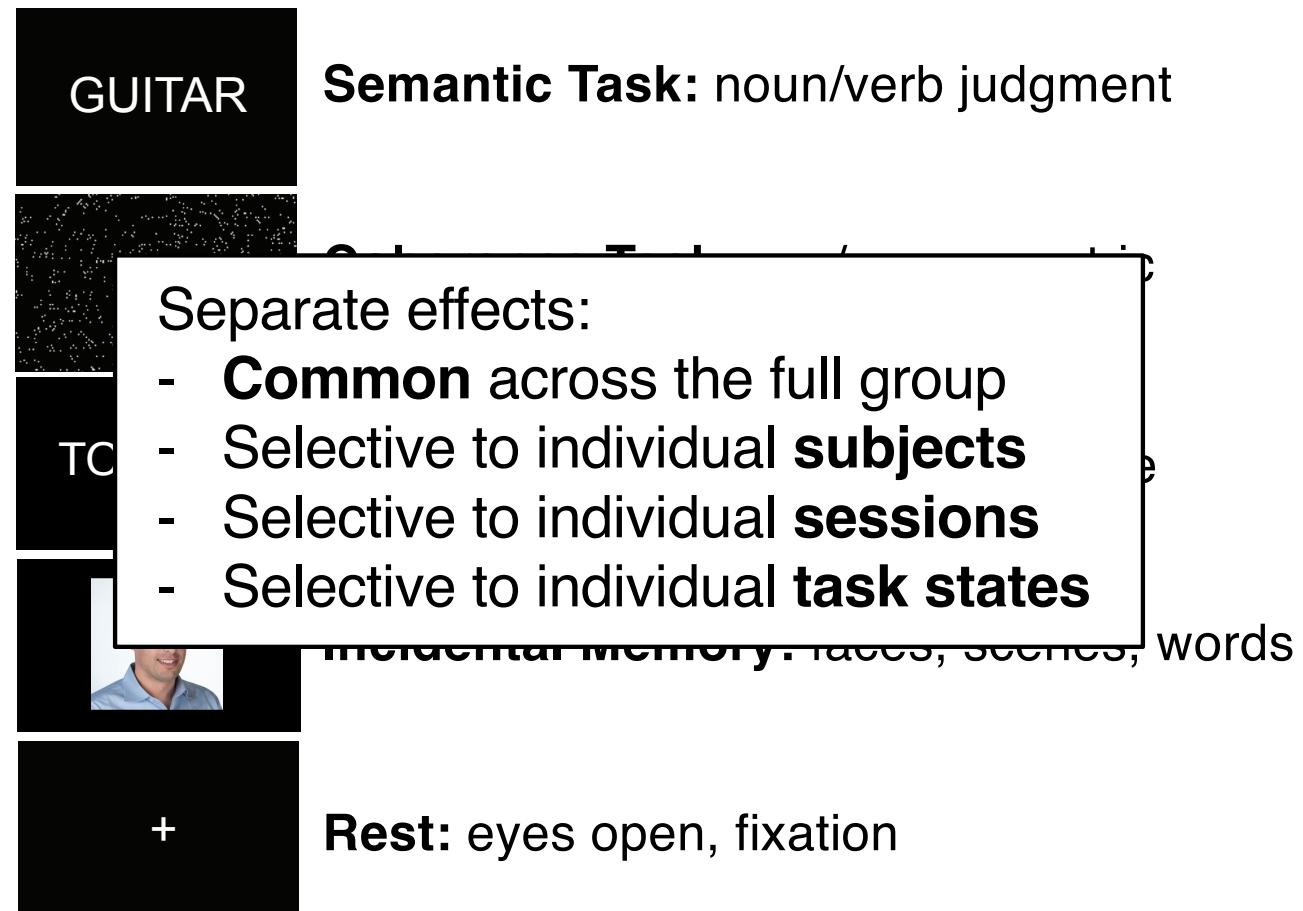
Are networks relatively more state or trait like?



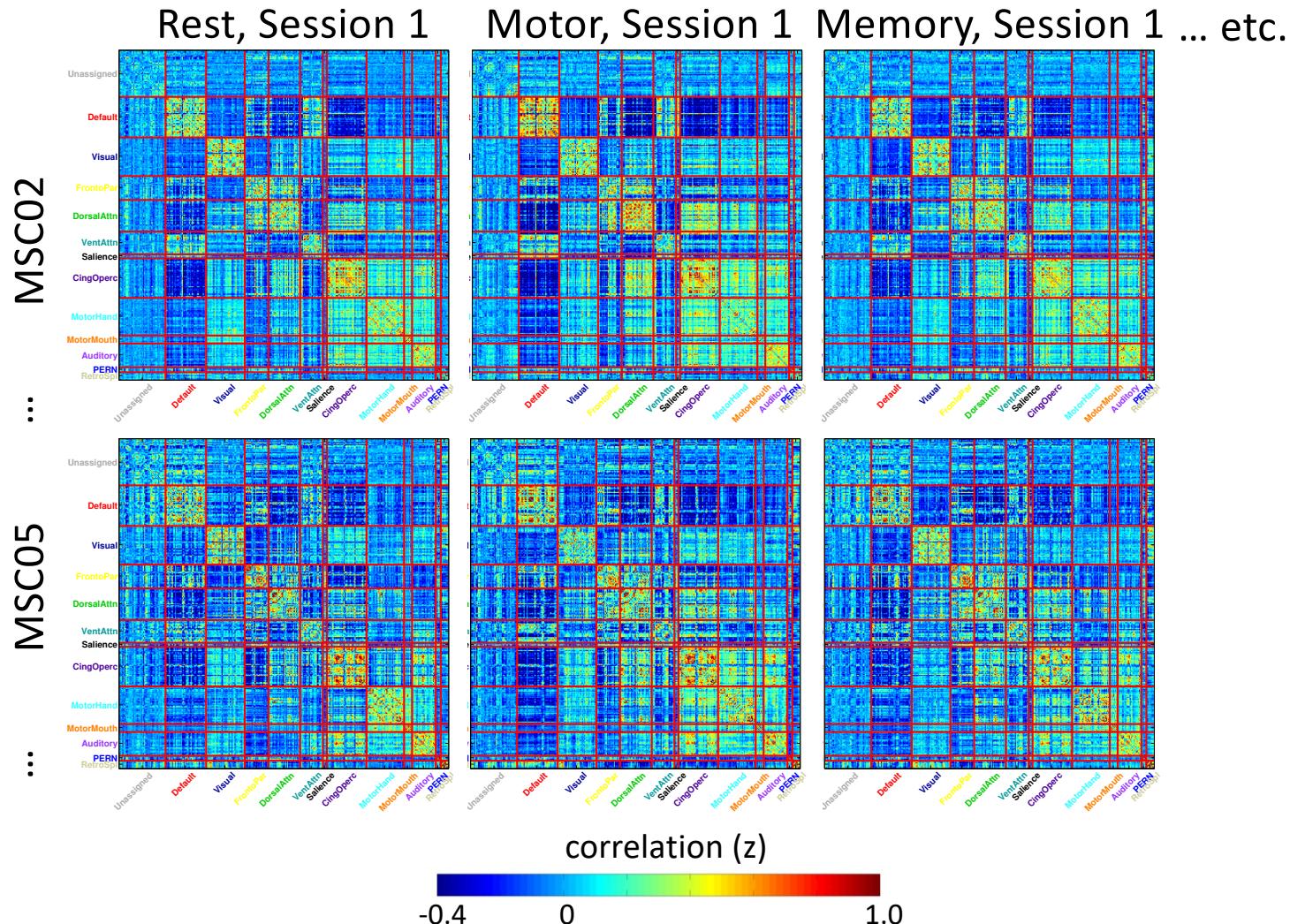
- **Interpretation** of resting-state fMRI differences
- **Applications** of resting-state fMRI



Precision fMRI: quantify stability vs. variability in functional networks

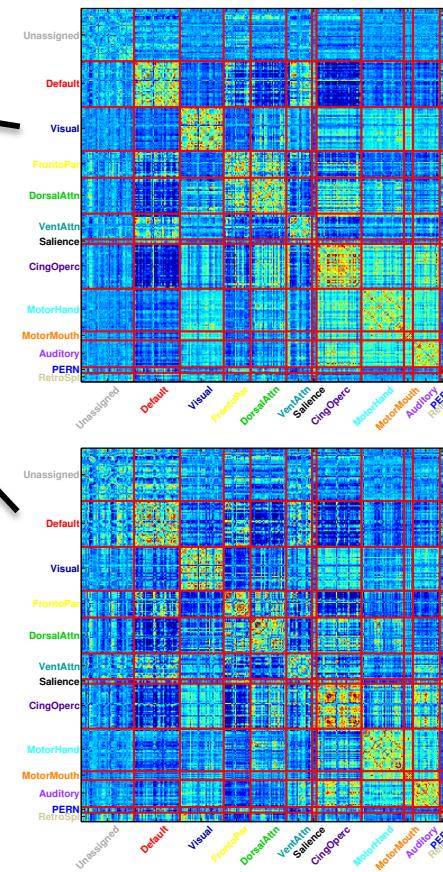
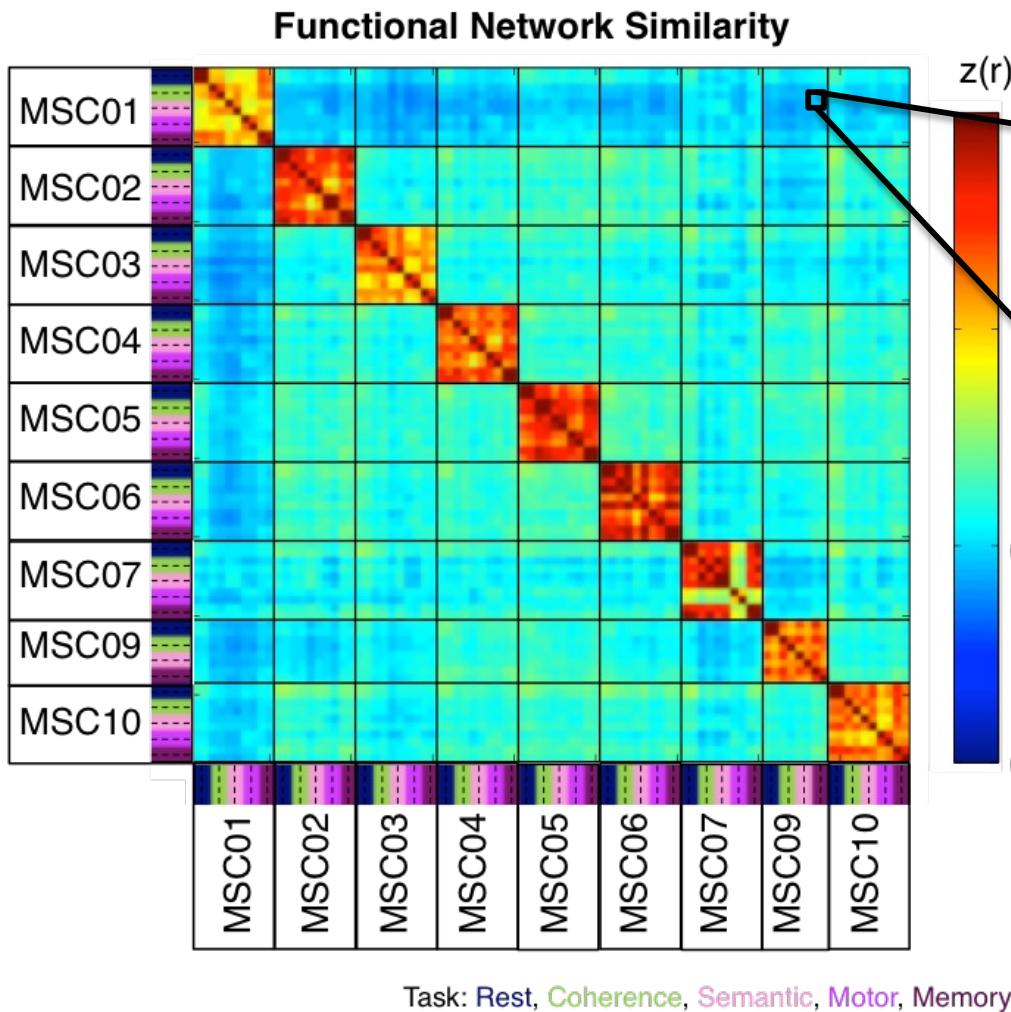


Functional networks were measured for each subject, session, and task



*Task networks measured with **background (residual) connectivity**

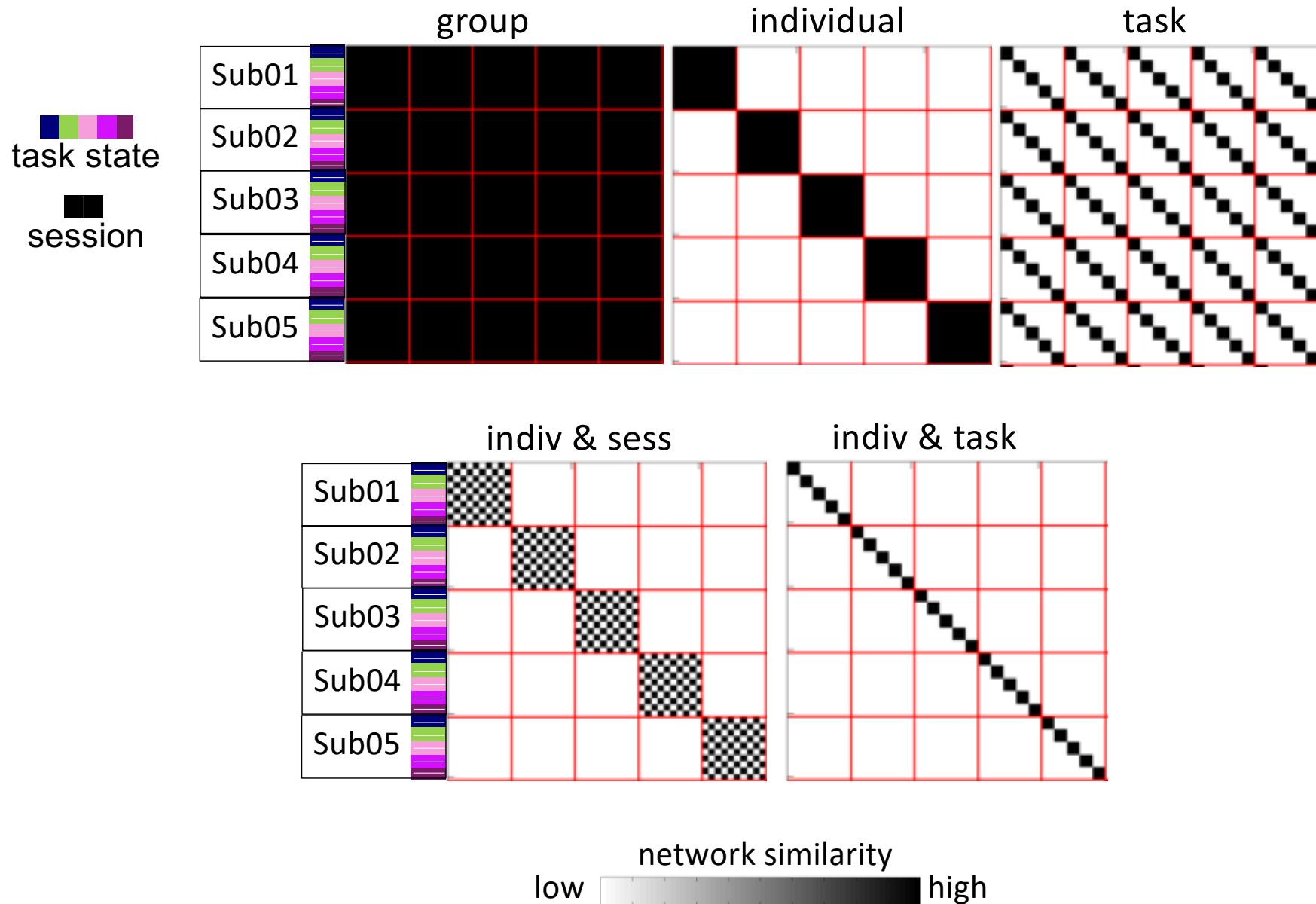
Functional networks were compared with one another



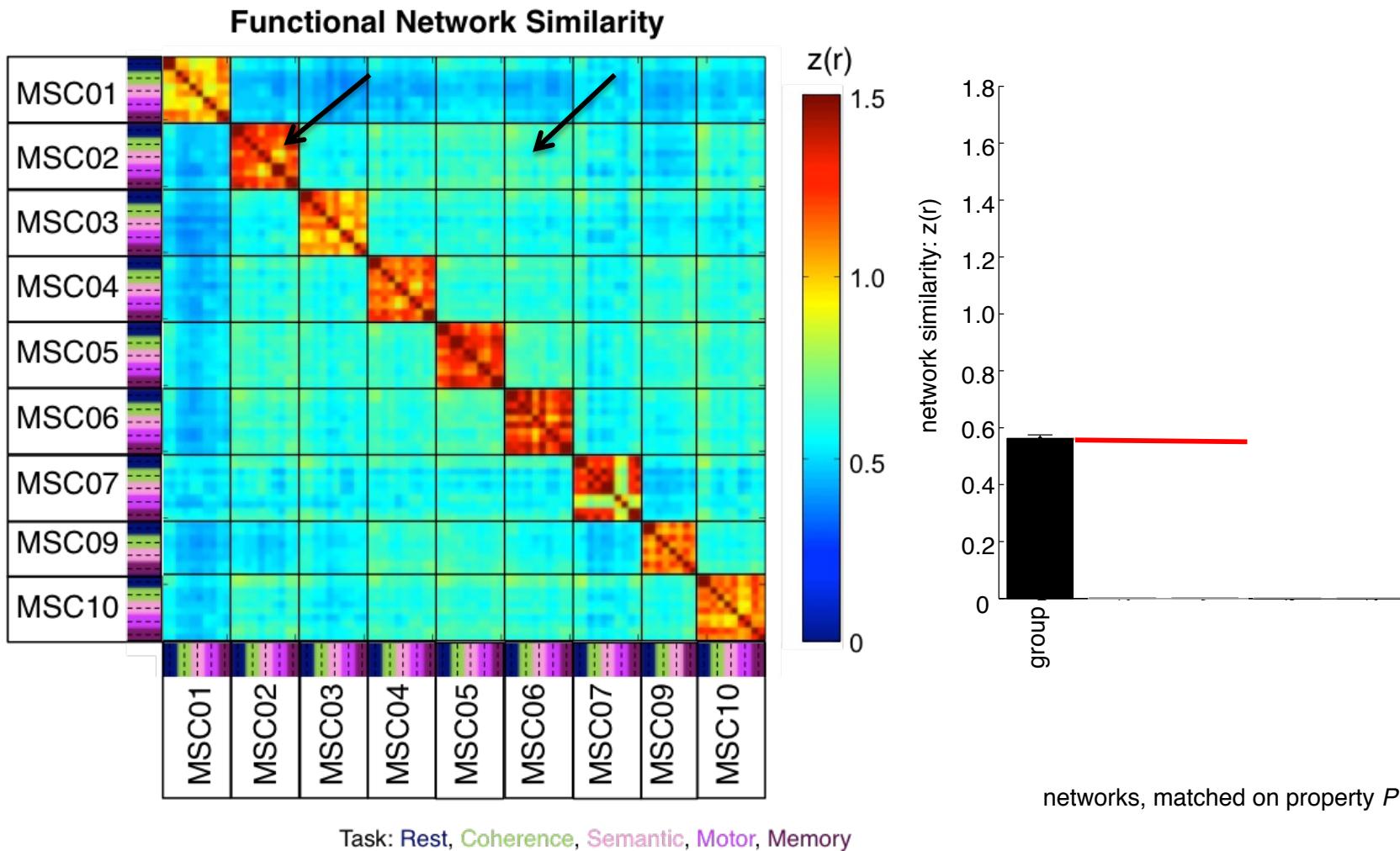
MSC01
Coherence Task
Session 1

MSC09
Semantic Task
Session 2

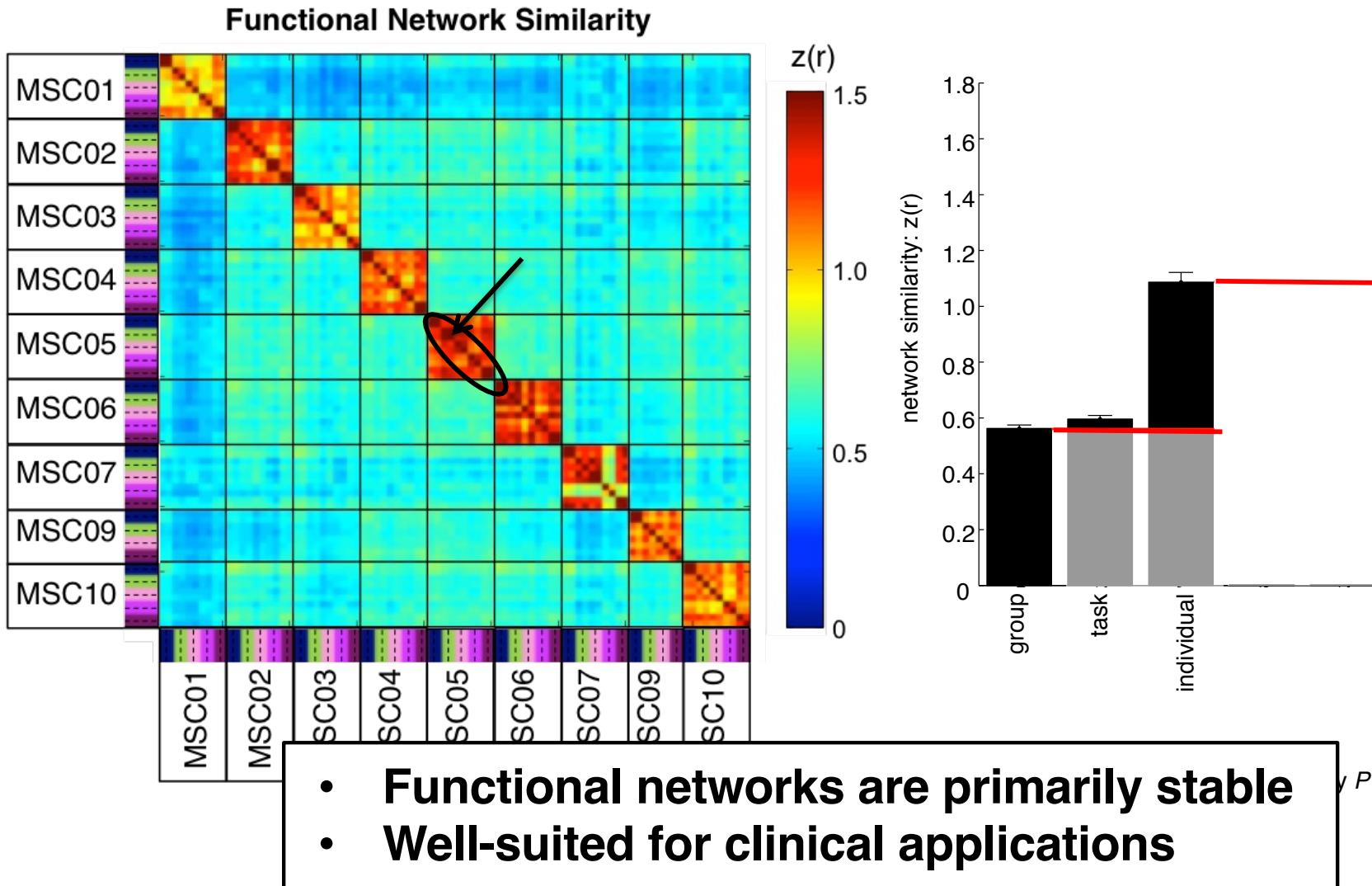
Quantification of the similarity among functional brain networks



Functional networks are dominated by stable factors



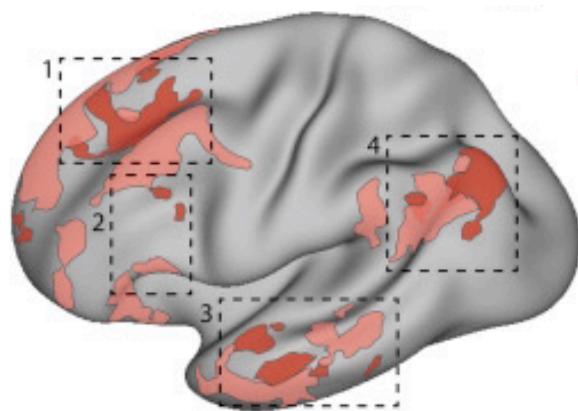
Functional networks are dominated by stable factors



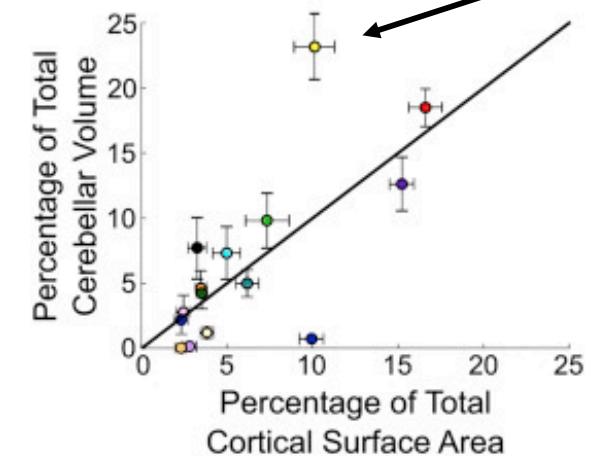
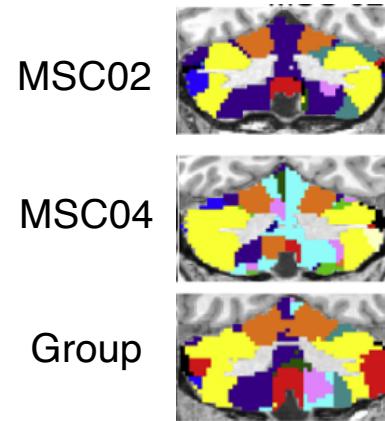
What can you do with precision fMRI?

2. Study basic properties of brain networks

Two 'default' networks Expanded frontoparietal network in the cerebellum



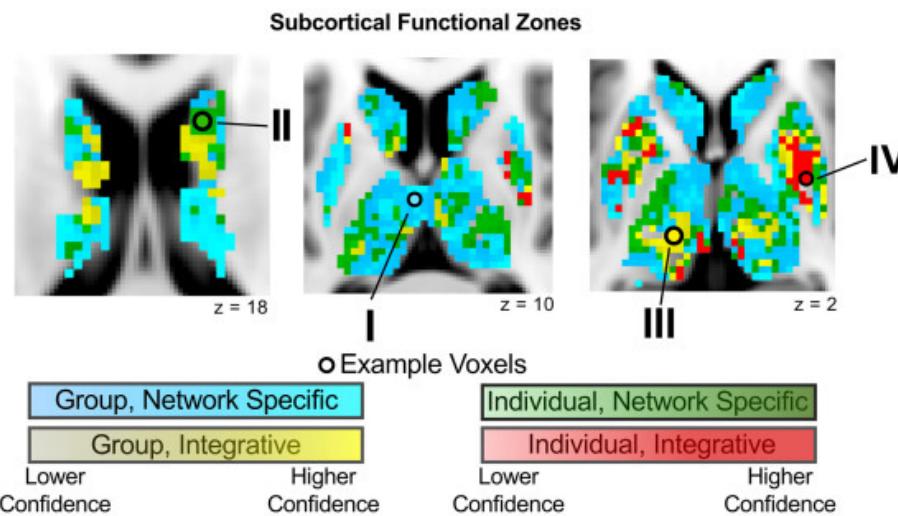
Braga, et al., 2017, *Neuron*



Marek, et al., 2018, *Neuron*

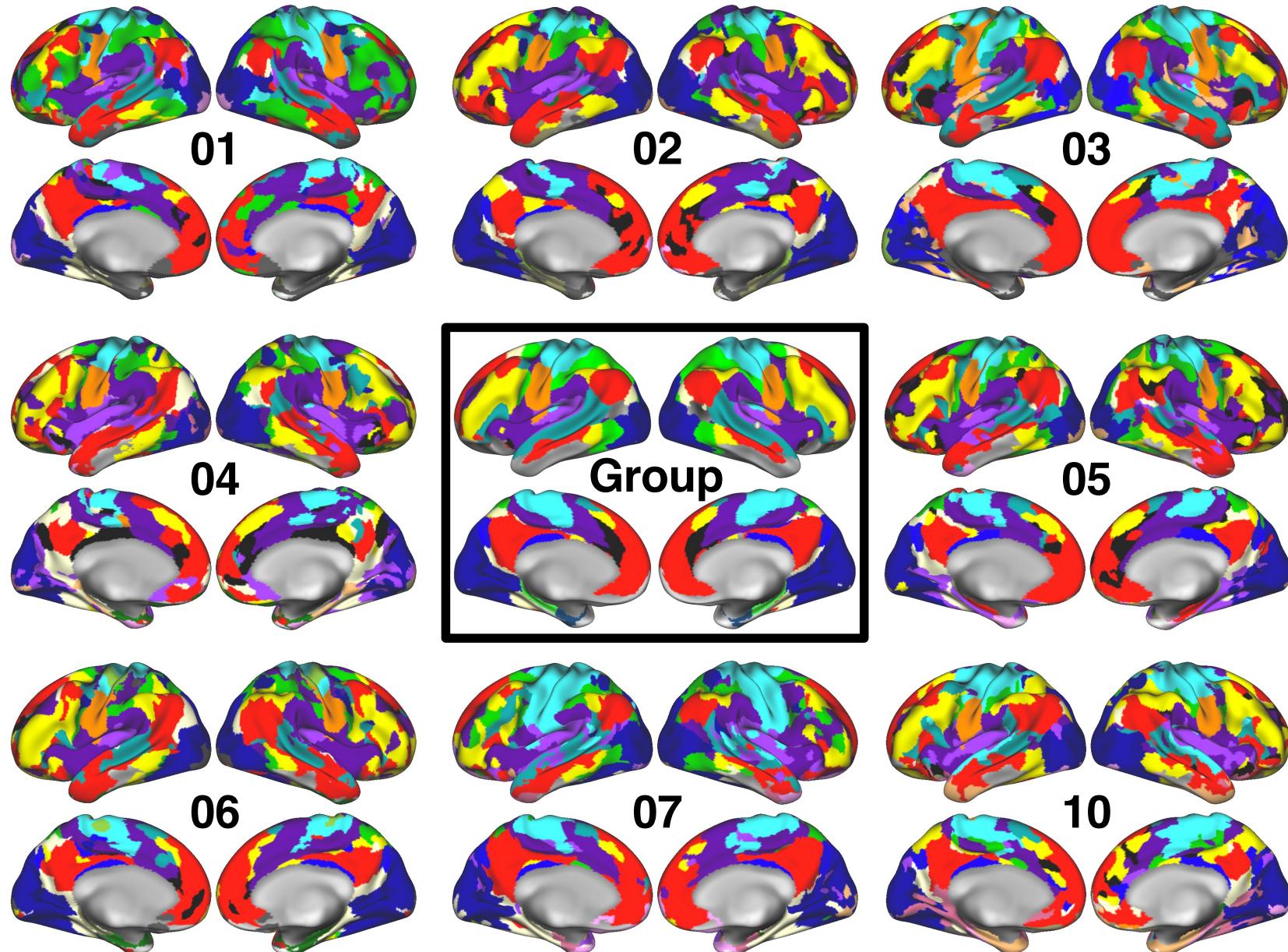
Integrative and network specific subcortical zones

Greene, et al., 2020, *Neuron*



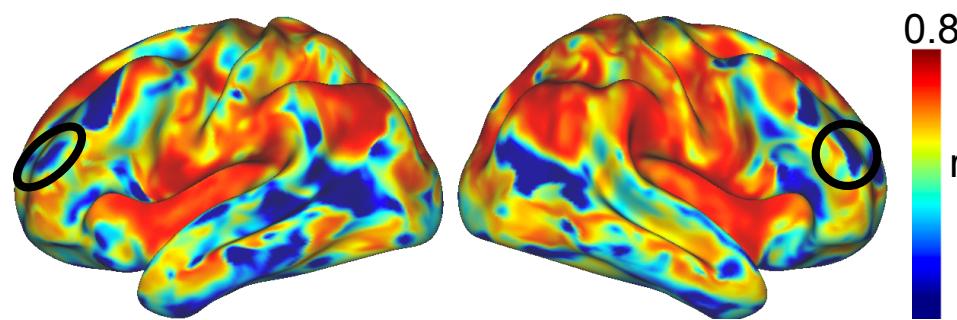
What can you do with precision fMRI?

3. Study individual differences in brain networks

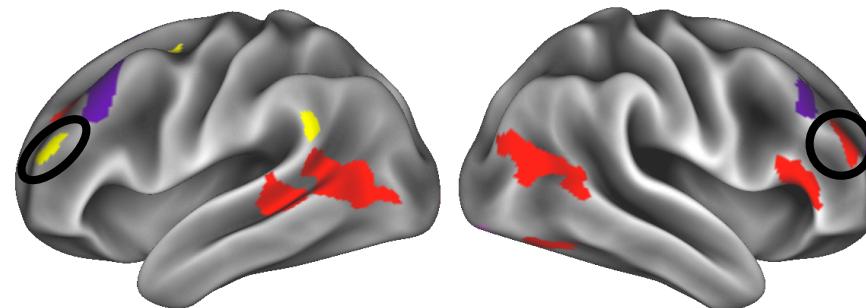


Precision fMRI and the characteristics of individual differences

spatial
correlation
MSC06 X group



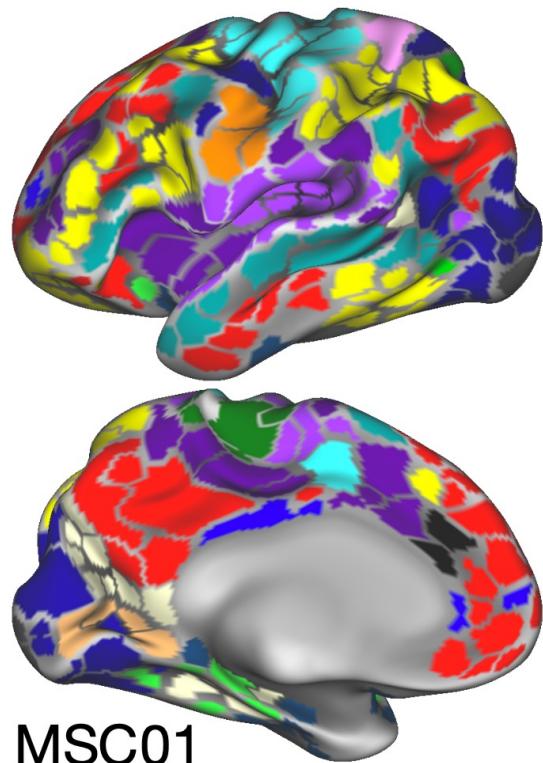
MSC06
variants
($r < 0.3$, SNR &
size masked)



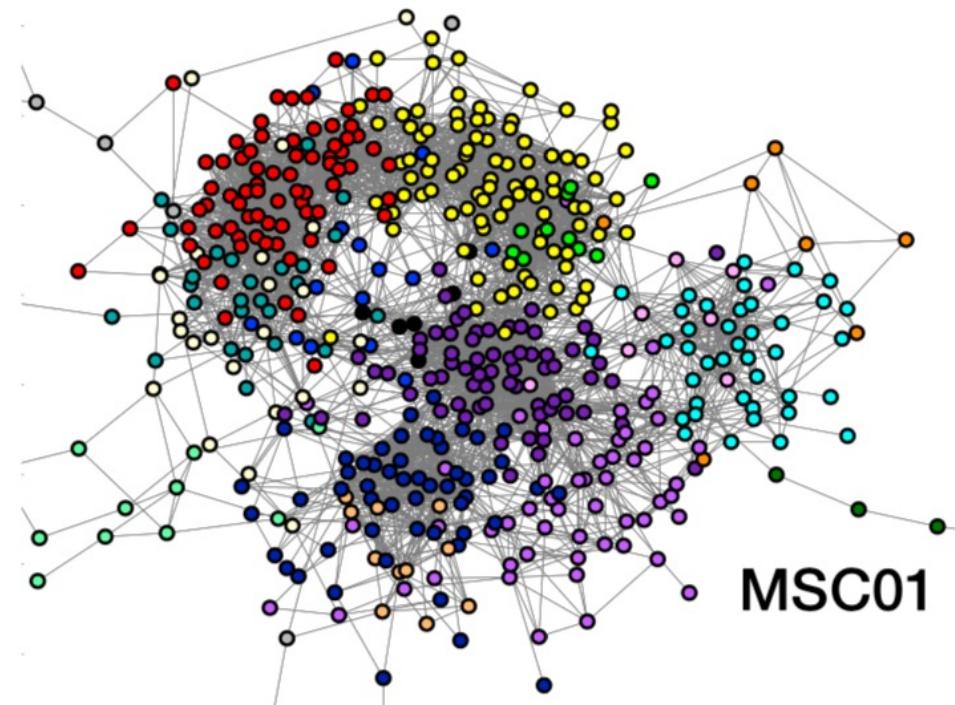
network variants



Precision fMRI and individual differences in graph structure

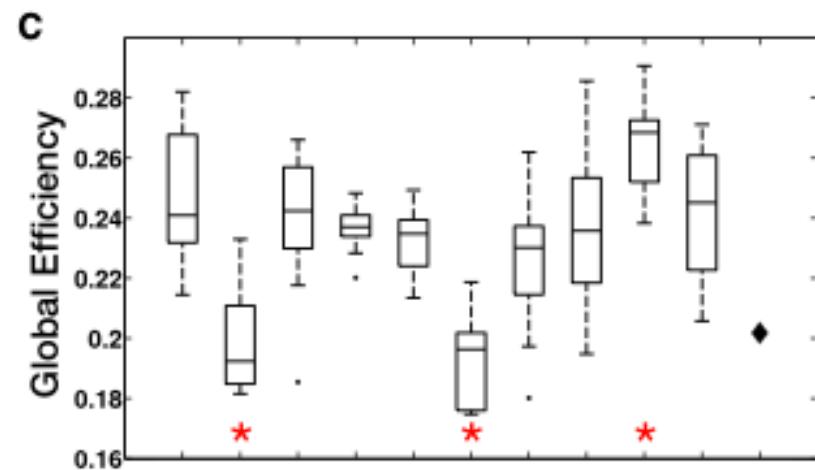
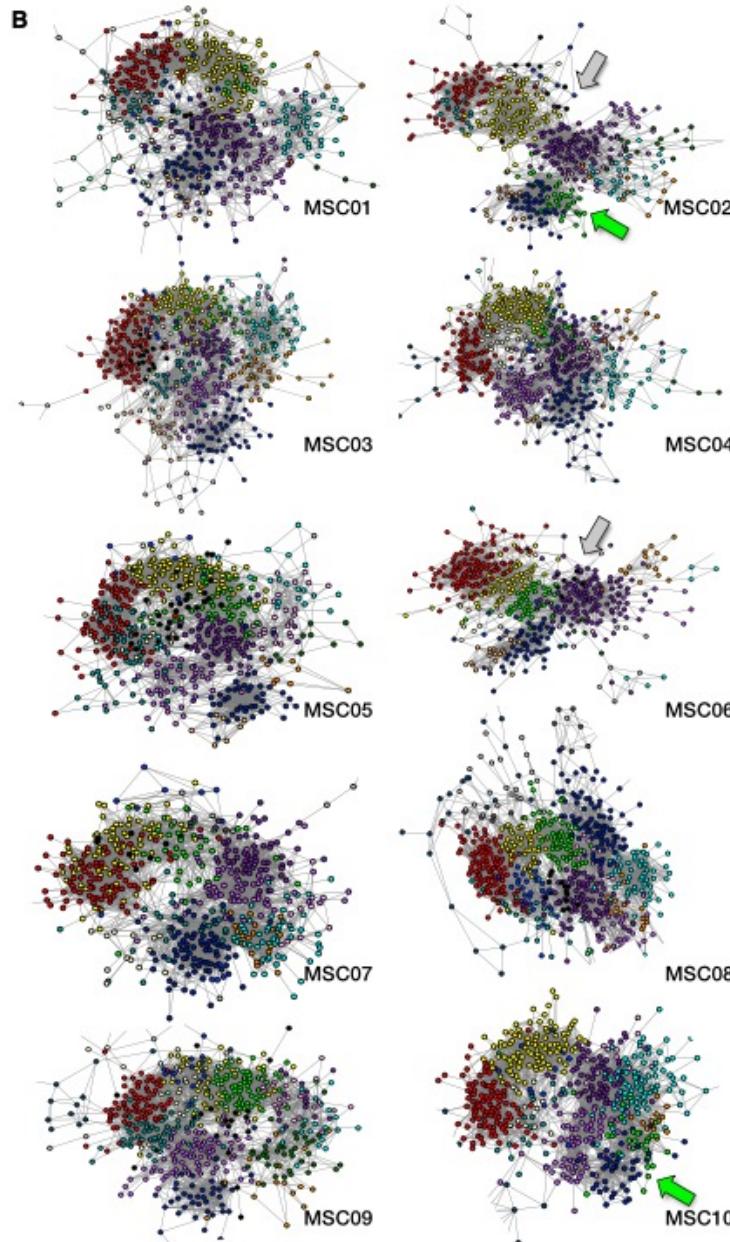


MSC01



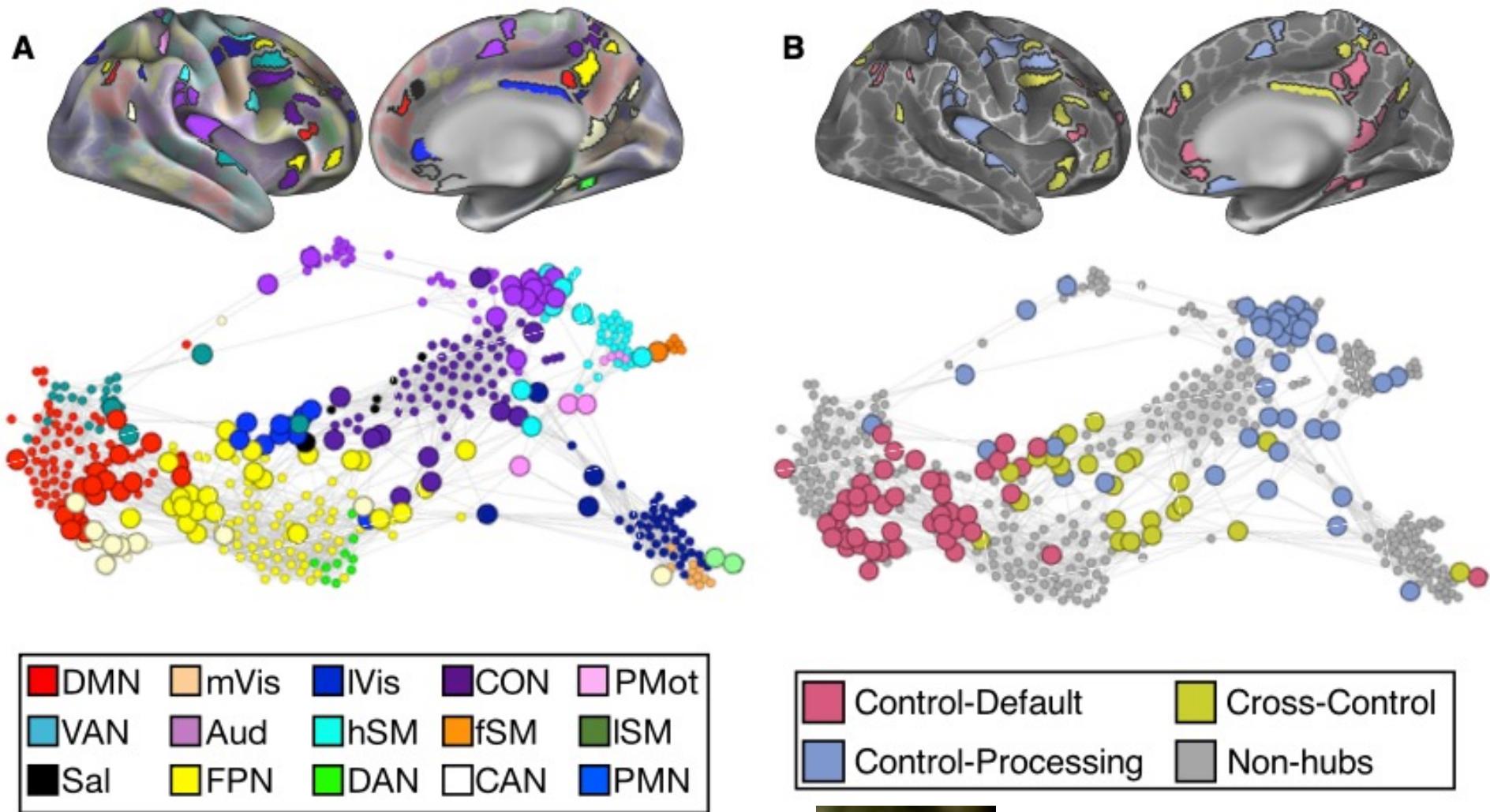
Gordon et al., 2017, Neuron

Precision fMRI and individual differences in graph structure



Gordon et al., 2017, Neuron

Precision fMRI and individual brain hubs



Gordon et al., 2018, Cell Reports

Talk Outline

1. Background: functional connectivity
2. Recent work: Individual 'precision' brain networks

3. Tutorial

Open up tutorial by either :

1. Logging in and running it on the JupyterHub:

<https://neurohackademy.2i2c.cloud/>

2. Cloning the repo and running it locally:

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<https://github.com/neurohackademy/nh2022-curriculum>

You may also want to download the following graph visualization software:

<https://gephi.org/>

Tutorial Outline: Four useful ways of looking at resting-state fMRI data

- 1. Grayplots:** looking at your data quality
- 2. Correlation Matrices:** Looking at functional correlations and their variability
- 3. Graphs:** Looking at some spring-embedded layouts of graphs
- 4. Hubs:** Estimating and plotting hub measures in graphs

“Grayplots” or “Carpet Plots”



Contents lists available at [ScienceDirect](#)

NeuroImage

journal homepage: www.elsevier.com/locate/neuroimage

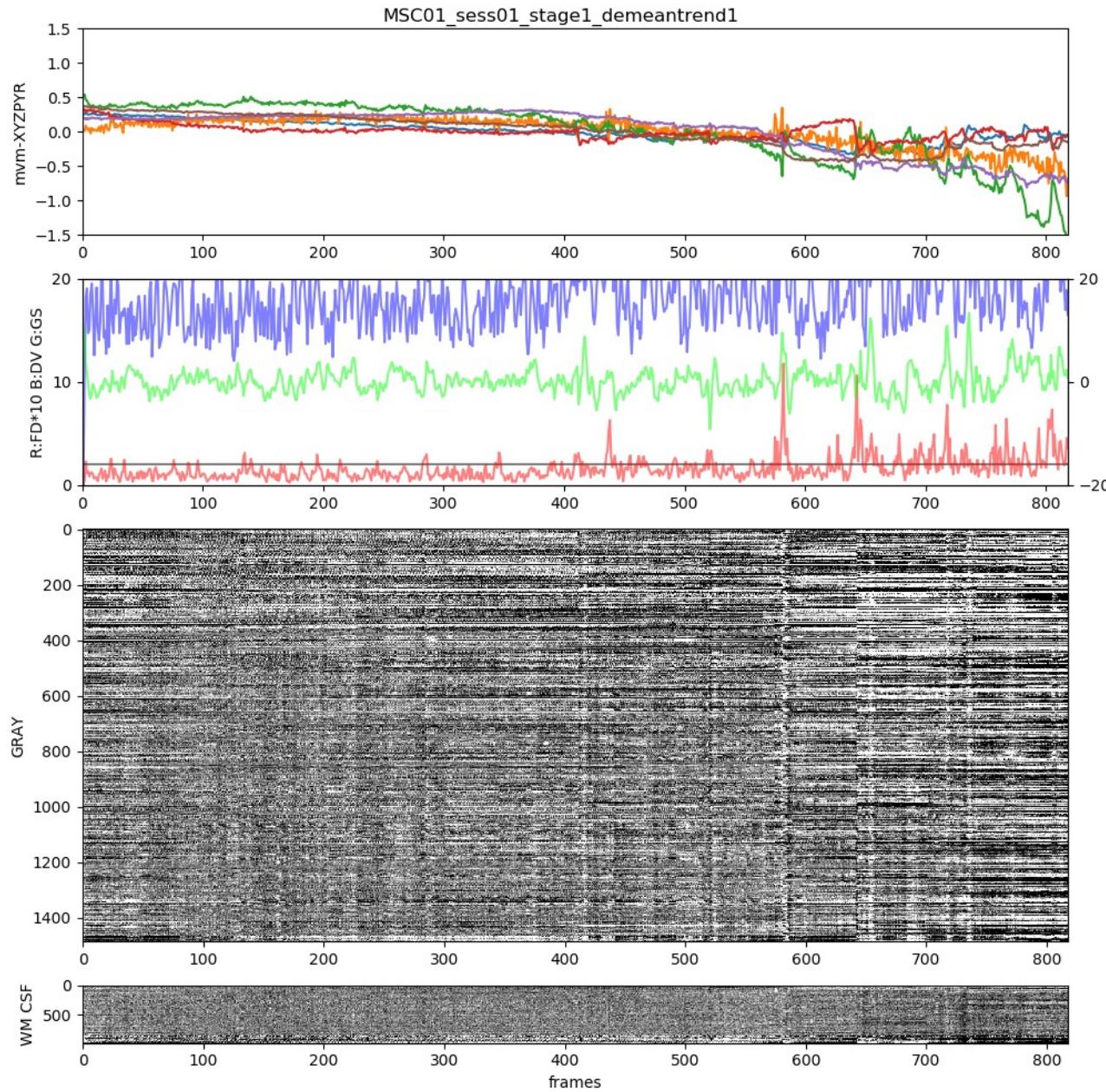
A simple but useful way to assess fMRI scan qualities

Jonathan D. Power

NIMH, National Institute for Mental Health, Building 10 Room 4C104, 10 Center Dr., Bethesda, MD 20814, USA

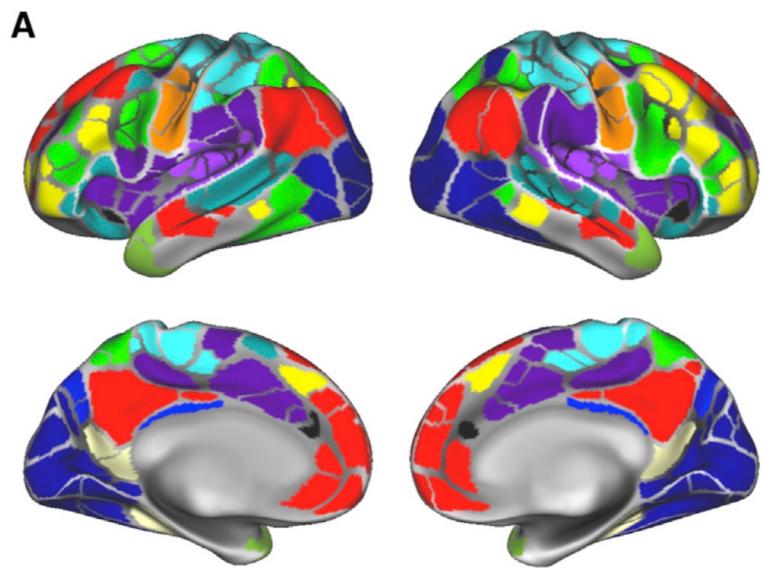
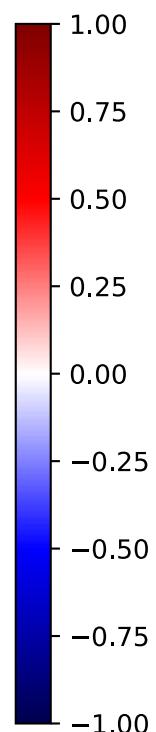
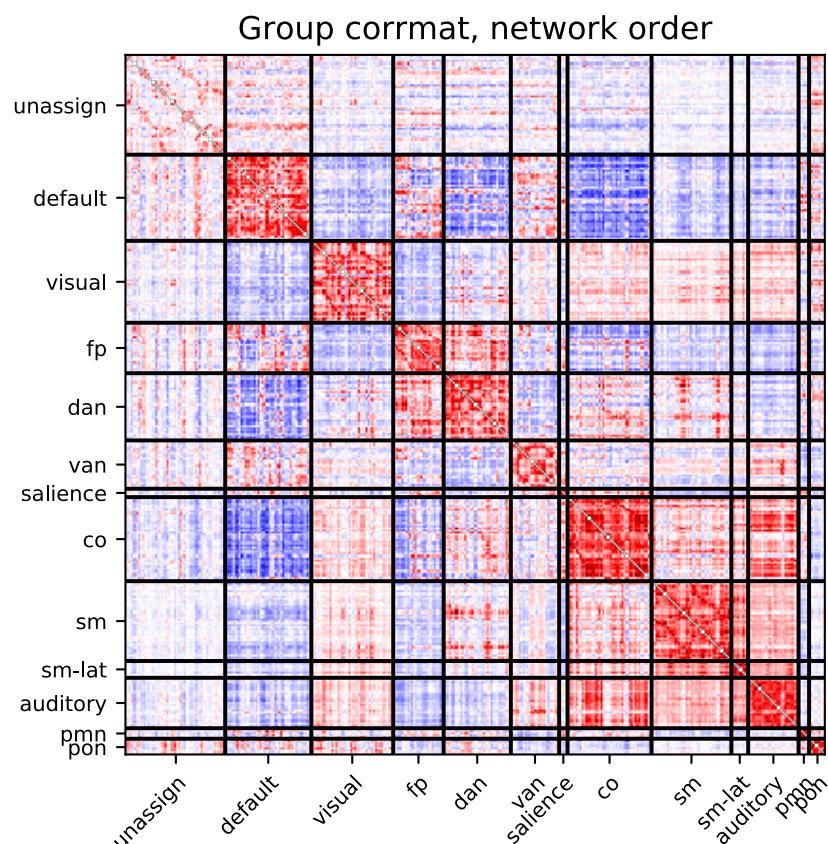
<https://fmriprep.readthedocs.io/en/stable/outputs.html>

“Grayplots” or “Carpet Plots”



Scaled to
+/- 2%
signal
change

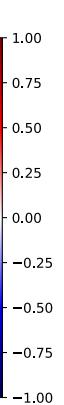
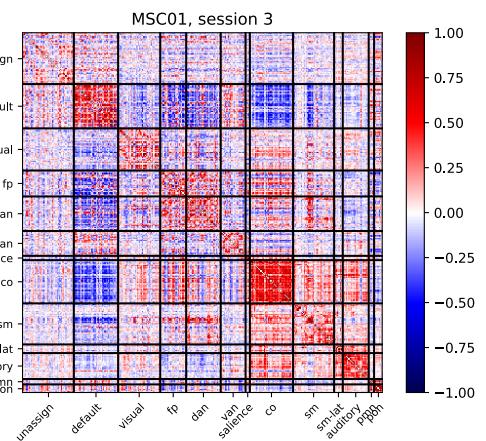
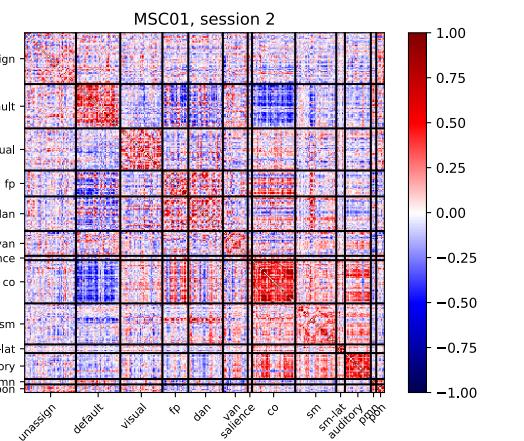
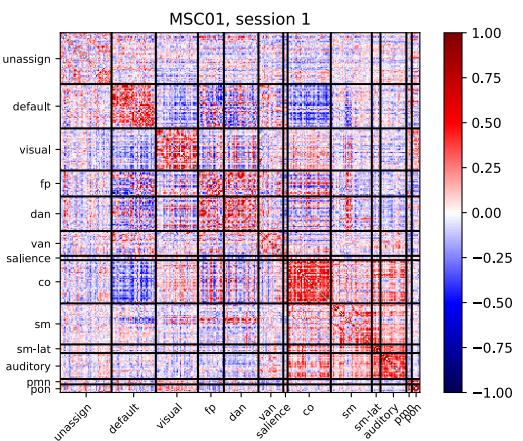
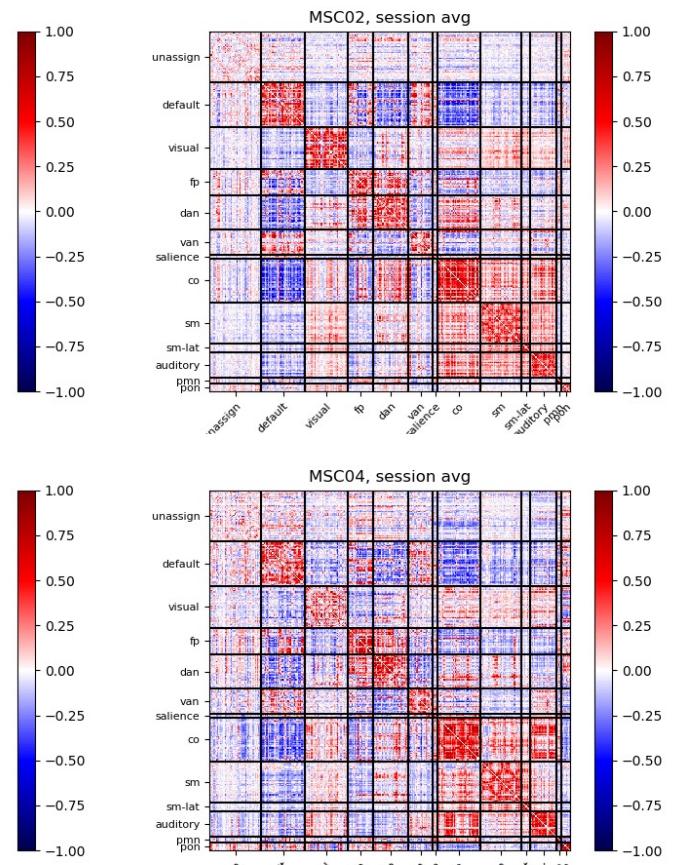
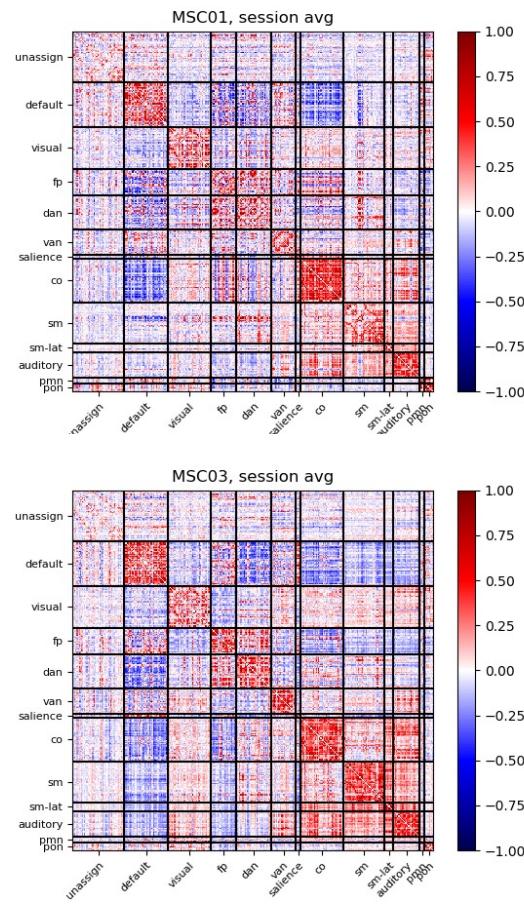
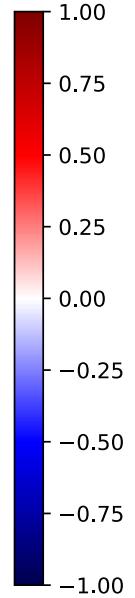
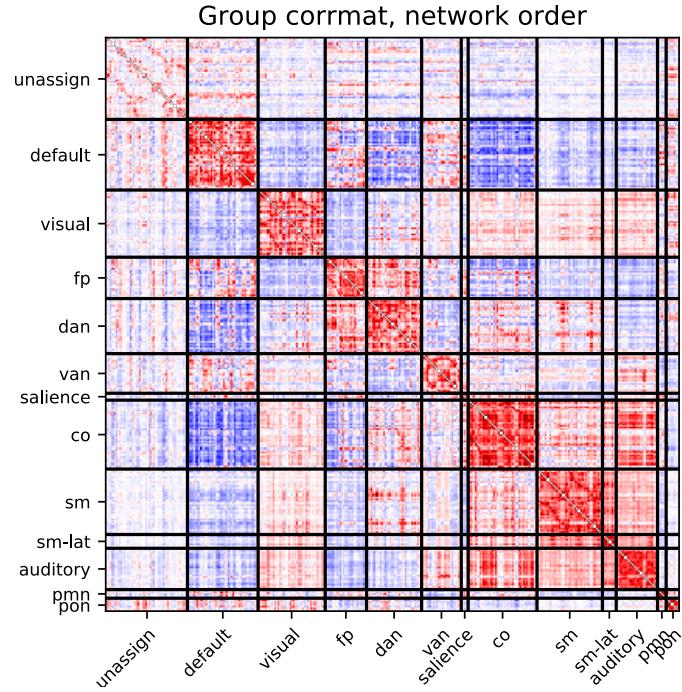
Correlation Matrices



Functional Networks

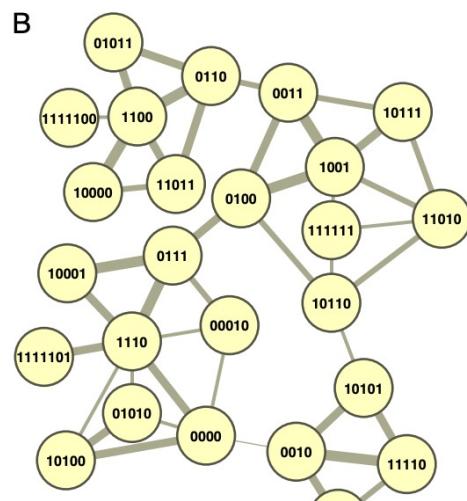
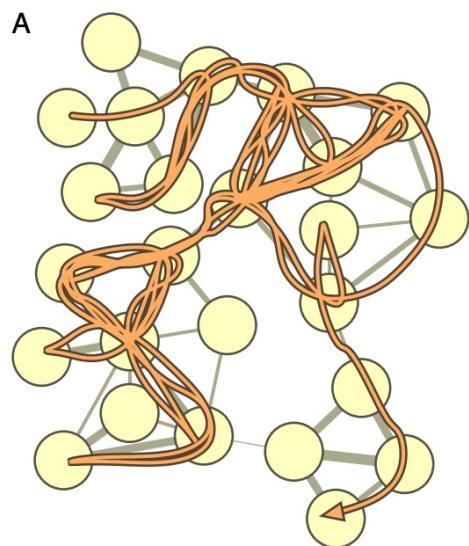
- Somatomotor (SM)
- Somatomotor lateral (SM-lat)
- Visual (Vis)
- Auditory (Aud)
- Cinguloopercular (CO)
- Frontoparietal (FP)
- Dorsal Attention (DAN)
- Ventral Attention (VAN)
- Salience (Sal)
- Default (DMN)
- Parietal Memory (PMN)
- Retrosplenial (RSP)

Correlation Matrices



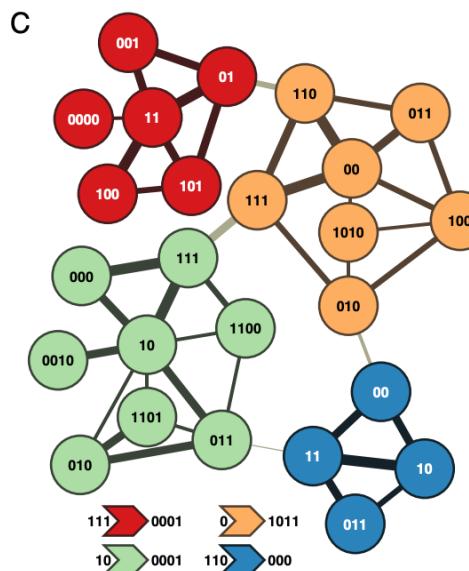
Correlation Matrices Aside: Defining Networks

Infomap



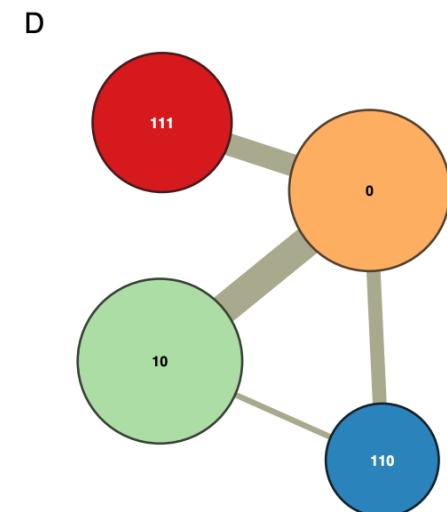
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1001 0100 0111 10001 1110 0111 10001 0111 1110 0000 1110 10001
0111 1110 0111 1110 111101 1110 0000 10100 0000 1110 10001 0111
0100 10110 11010 10111 1001 0100 1001 10111 1001 0100 1001 0100
0011 0100 0011 0110 11011 0110 0011 0100 10111 0011 0111 0110 0100
00011

314 bits



111 0000 11 01 101 100 101.01 0001.0 110 011 00 110 00 111 1011 10
111 000 10 111 000 111 10 011 10 000 111 10 111 10 0010 10 011 010
011 10 000 111 0001 0 111 010 100 011 00 111 00 011 00 111 00 111
110 111 110 1011 111 01 101 01 0001 0 110 111 00 011 110 111 1011
10 111 000 10 000 111 0001 0 111 010 1010 010 1011 110 00 10 011

243 bits

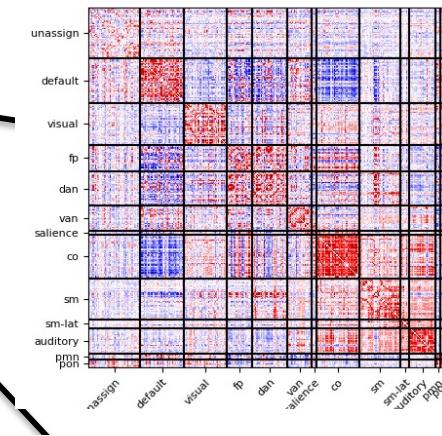
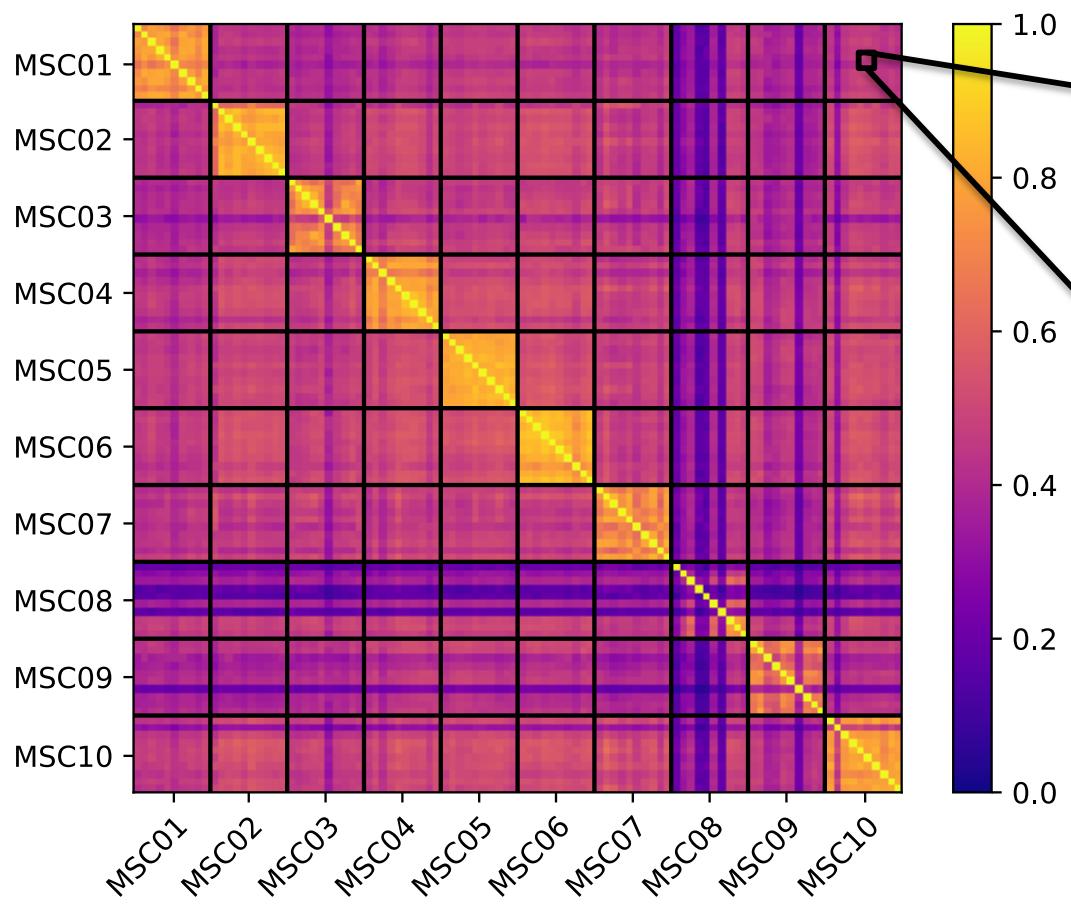


111 0000 11 01 101 100 101 01 0001 0 110 011 00 110 00 111 1011 10
111 000 10 111 000 111 10 011 10 000 111 10 111 10 0010 10 011 010
011 10 000 111 0001 0 111 010 100 011 00 111 00 011 00 111 00 111
110 111 110 1011 111 01 101 01 0001 0 110 111 00 011 110 111 1011
10 111 000 10 000 111 0001 0 111 010 1010 010 1011 110 00 10 011

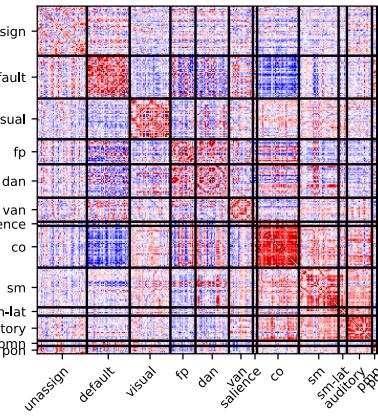
<https://www.mapequation.org/>

Rosvall & Bergstrom, 2008, PNAS

Correlation Matrices - Similarity



MSC01
Session 5



MSC10
Session 5

Correlation Matrices Aside: Defining Networks

Physics Reports 486 (2010) 75–174



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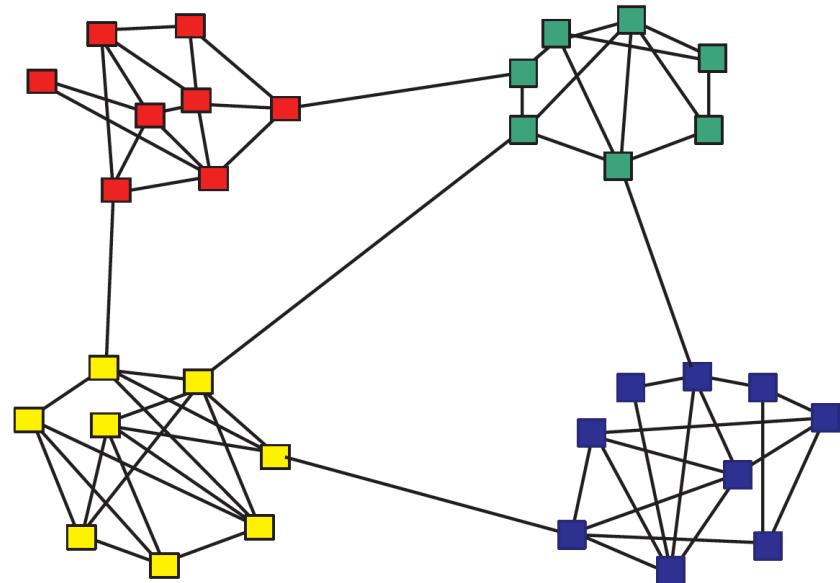
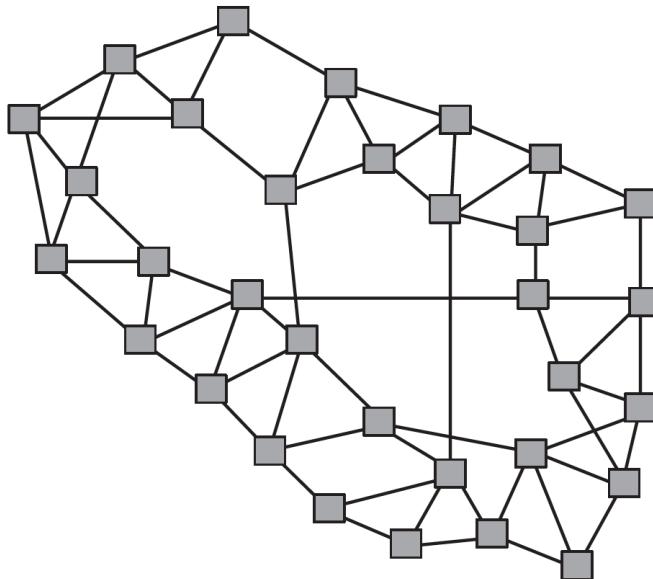
Community detection in graphs

Santo Fortunato*

Complex Networks and Systems Lagrange Laboratory, ISI Foundation, Viale S. Severo 65, 10133, Torino, I, Italy

Correlation Matrices Aside: Defining Networks

Modularity Maximization

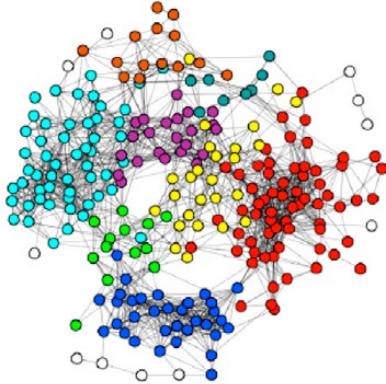


Newman's Modularity (Q)

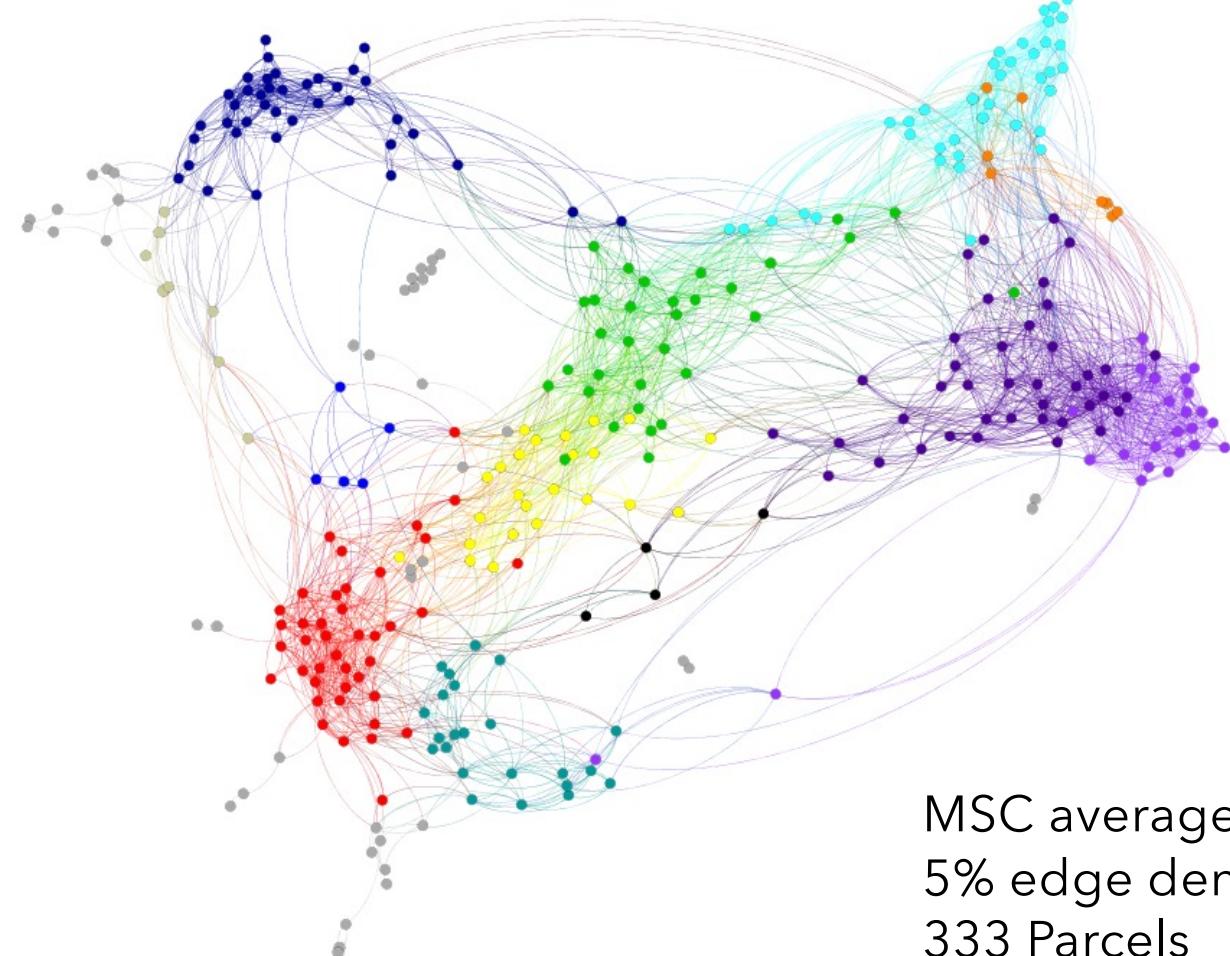
$$Q = \sum_{i=1}^m (e_{ii} - a_i^2)$$

e = fraction of edges within a module
 a = fraction of edges between node in module to any other node

Graphs of Brain Networks



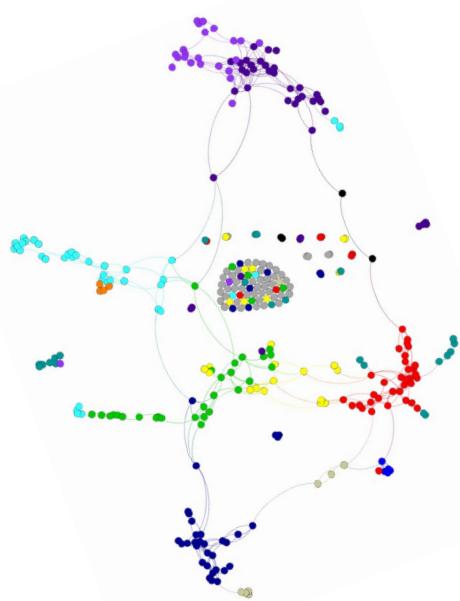
Power et al., 2014
120 person average
264 Power regions



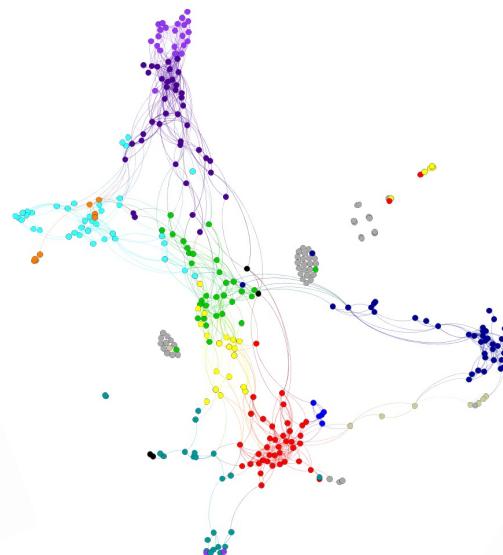
MSC average
5% edge density
333 Parcels
Gephi Force Layout

Graphs of Brain Networks

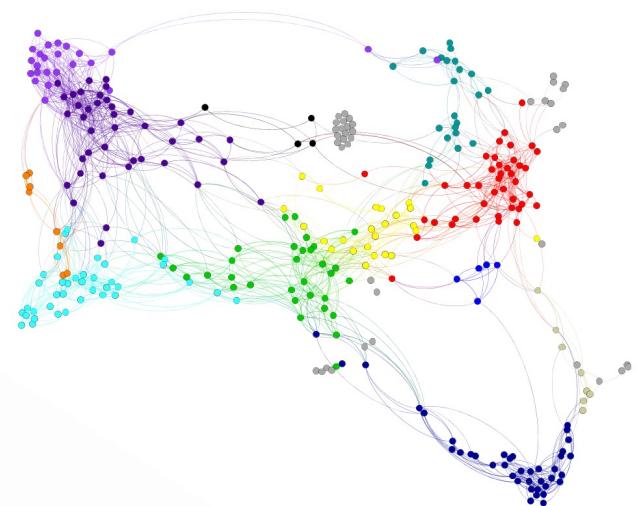
1%*



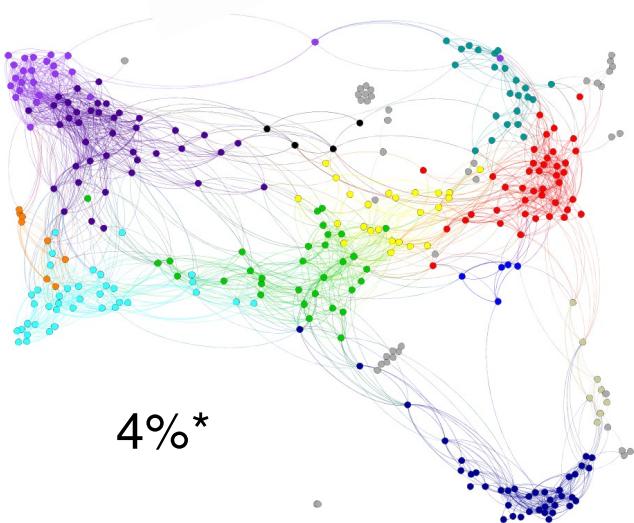
2%



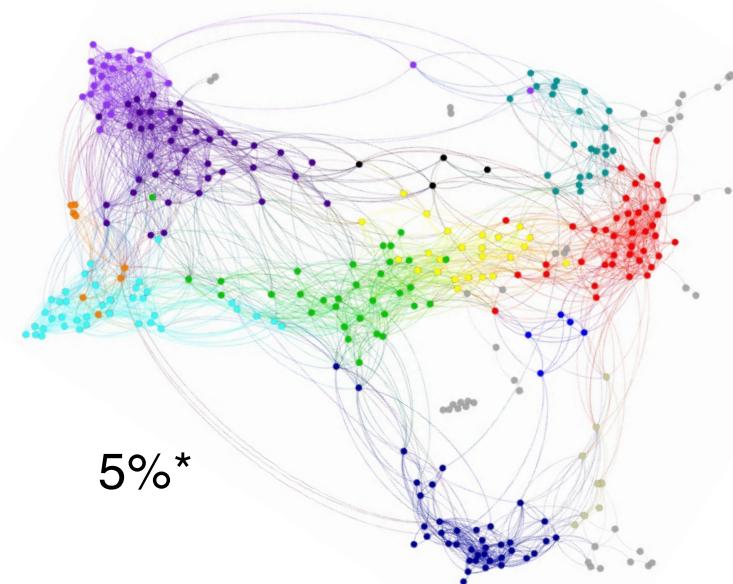
3%



4%*

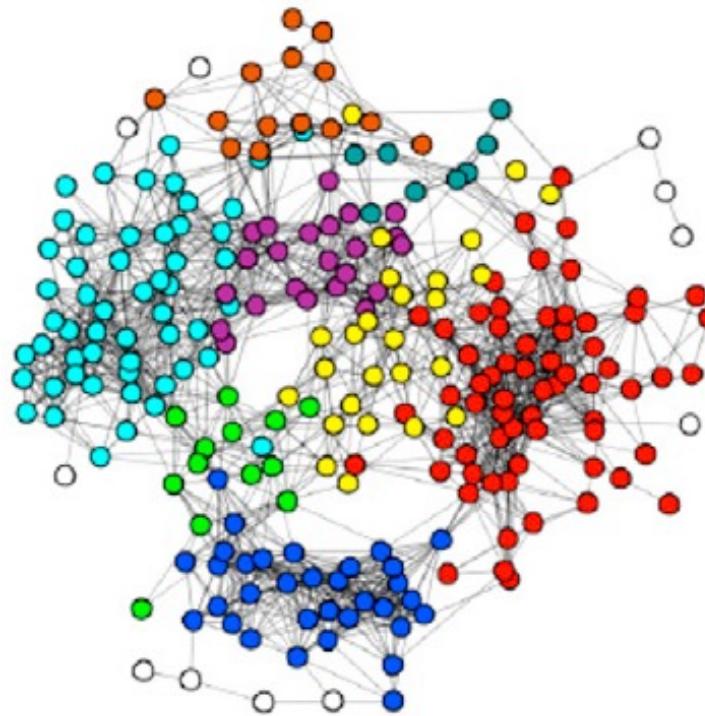


5%*



*flipped/rotated

Hub Measures

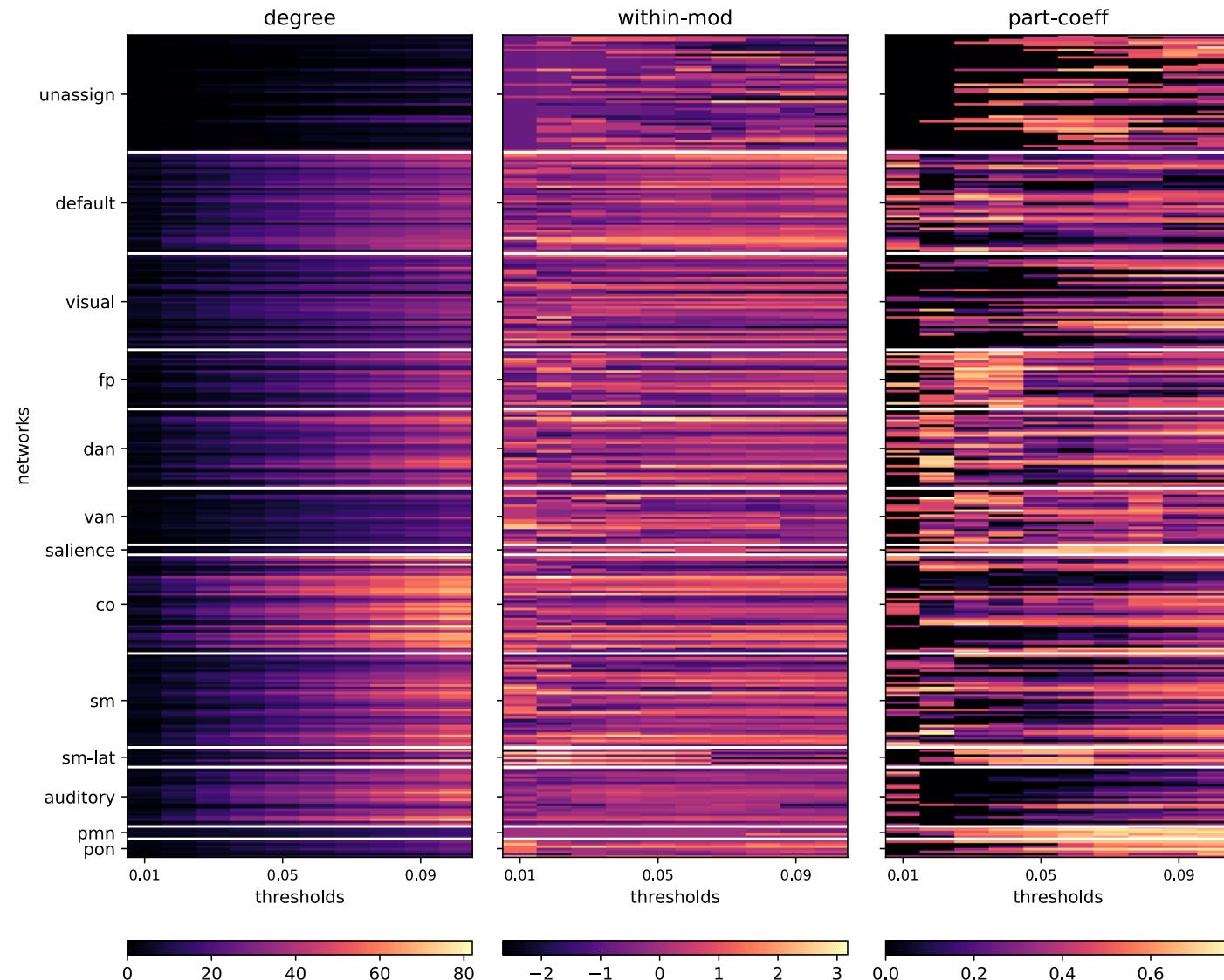


Degree: number of connections to a node

Within-module degree: normalized number of connections of a node to its module

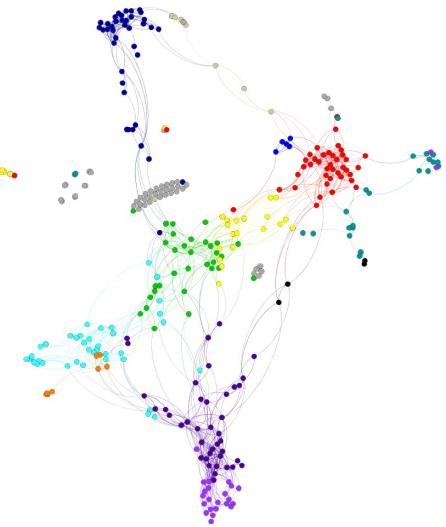
Participation coefficient: distribution of a node's connections across modules

Hub Measures

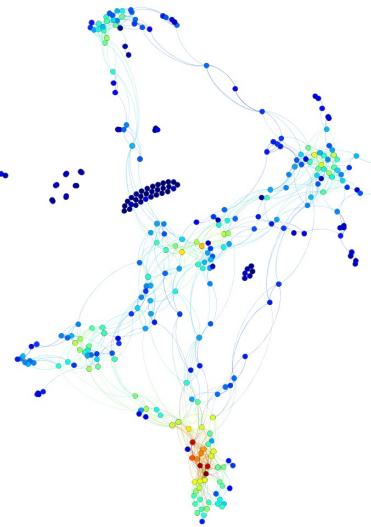


Hub Measures

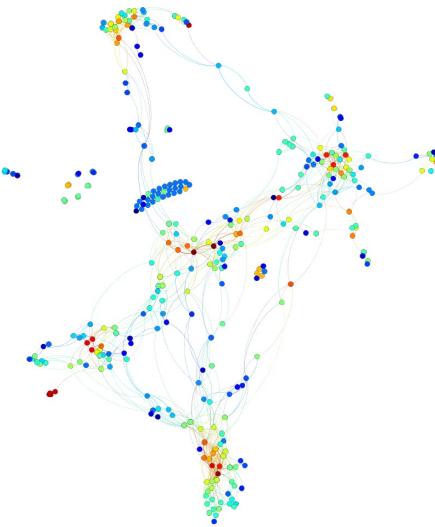
network



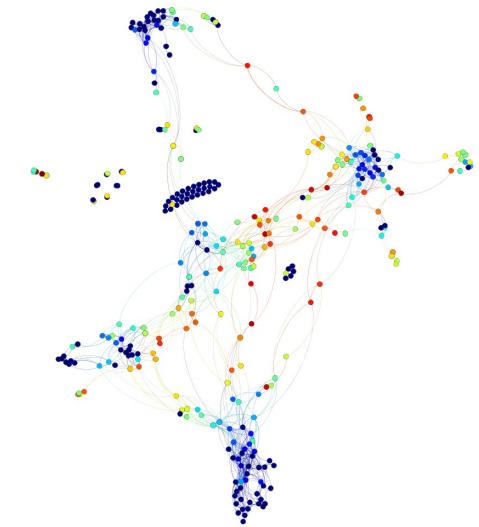
degree



within mod degree



participation coefficient



Degree: number of connections to a node

Within-module degree: normalized number of connections of a node to its module

Participation coefficient: distribution of a node's connections across modules

Thank You!