

Measuring human functional brain networks

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Assistant Professor

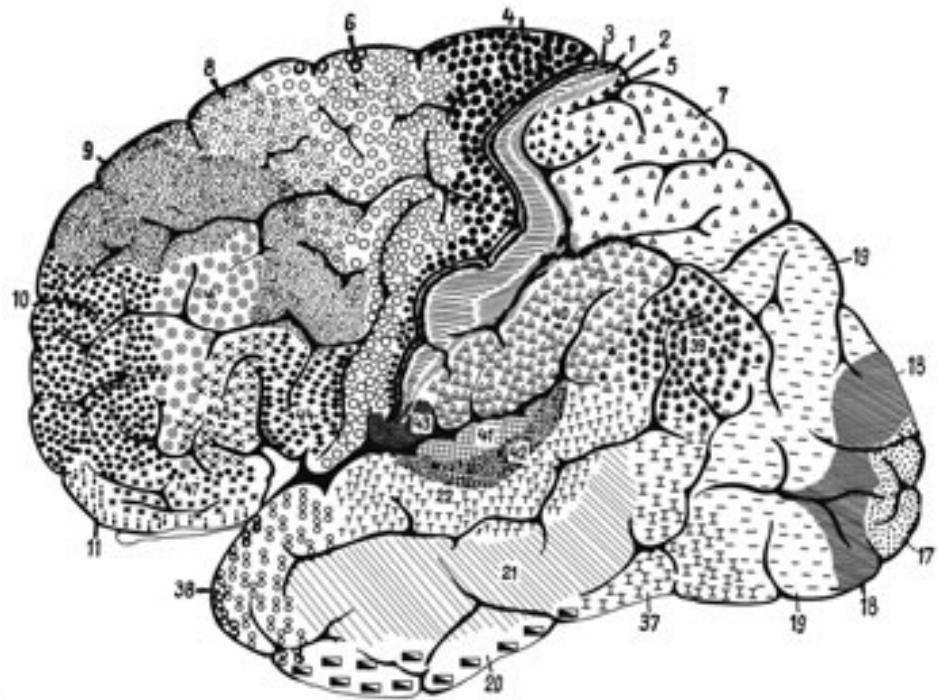
Psychology Department
Northwestern University

grattonlab.org



Two viewpoints on cognition & brain function

specialized processing



coordinated interactions



Talk Outline

1. Background: functional connectivity
2. Recent work: Forms of variation in functional brain networks
3. Tutorial

Open up tutorial by either :

1. Cloning the repo and running it locally:
https://github.com/cgratton/Neurohackademy_Tutorial.git
2. Logging in and running it on the JupyterHub.

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

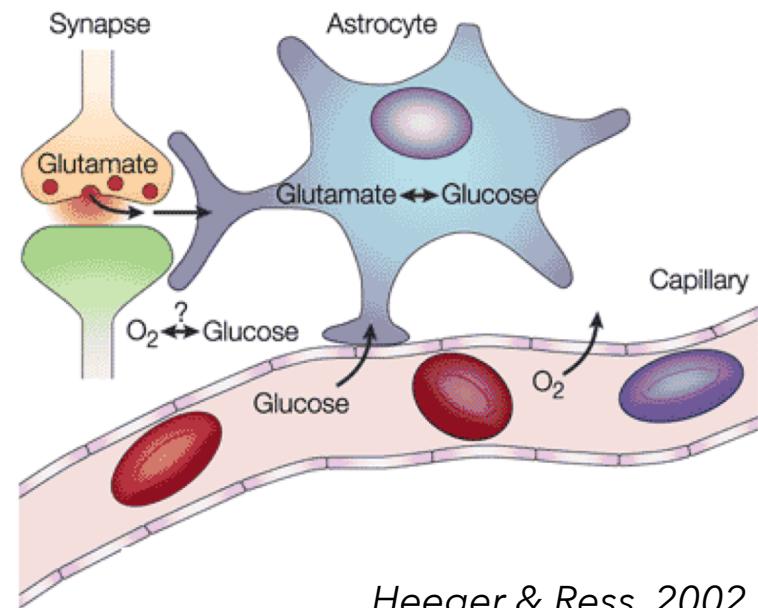
<https://gephi.org/>

Talk Outline

- 1. Background: functional connectivity**
2. Recent work: Forms of variation in functional brain networks
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functional Magnetic Resonance Imaging (fMRI)

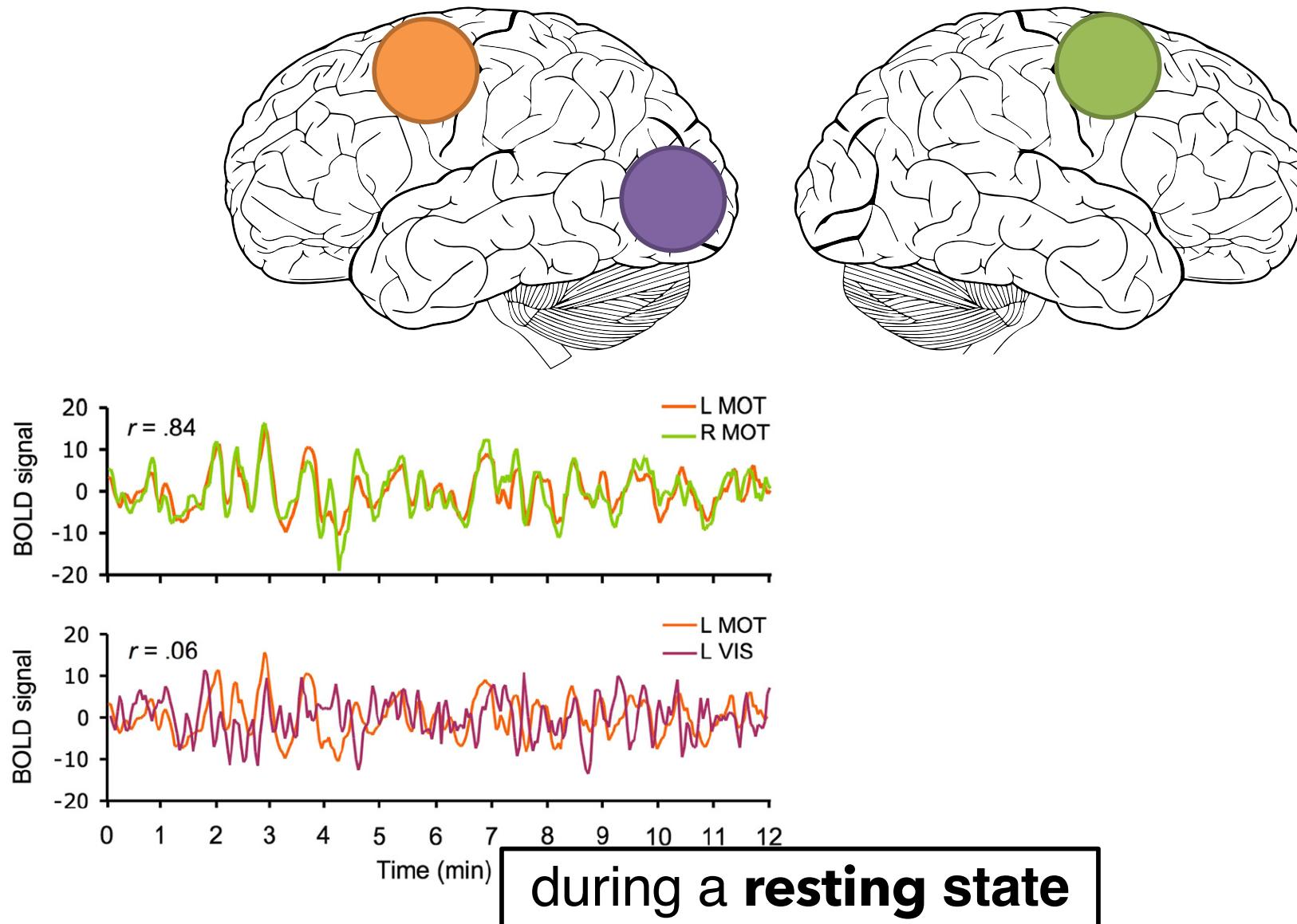
Blood Oxygen Level Dependent (BOLD) Signal



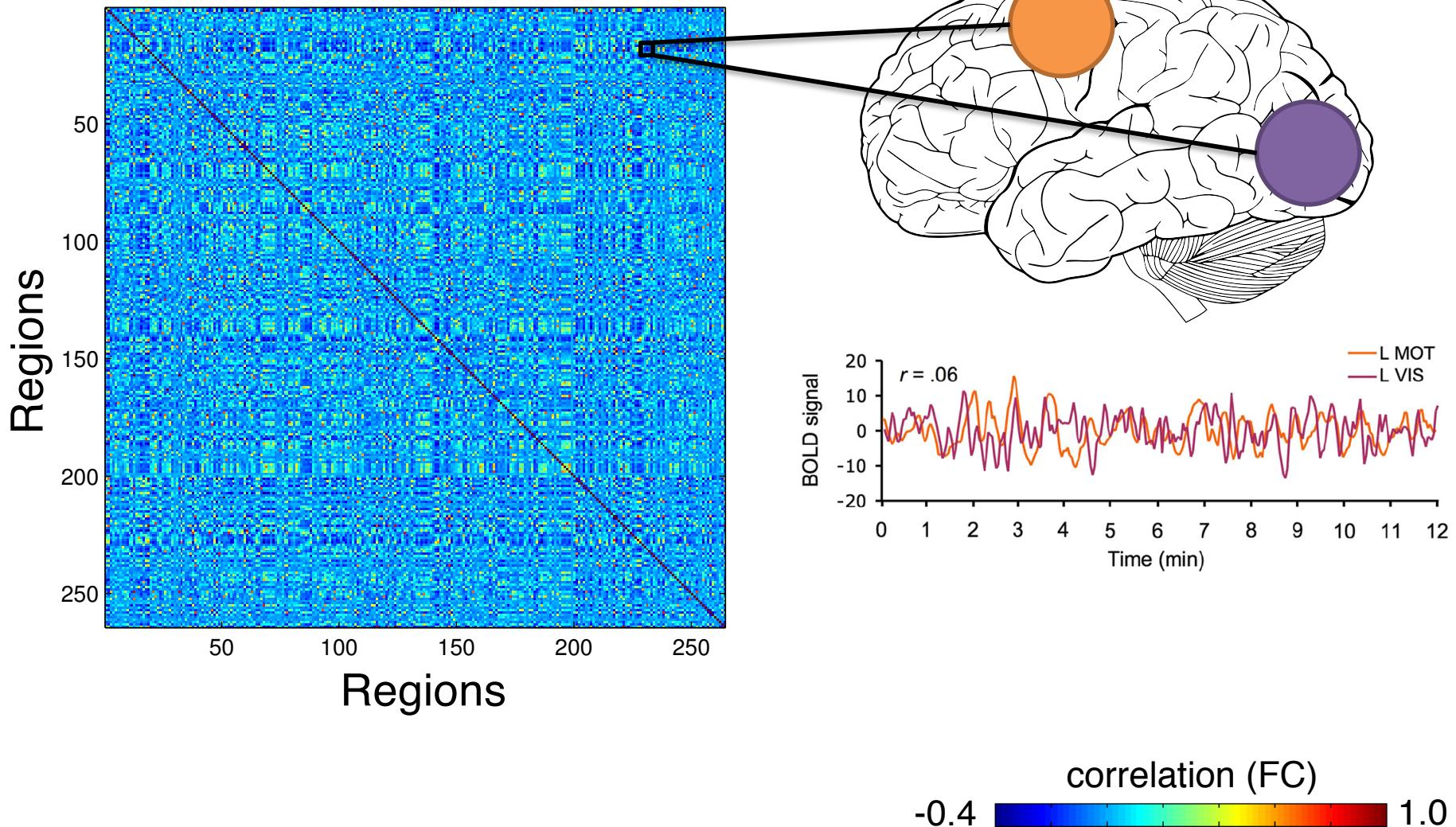
Heeger & Ress, 2002

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

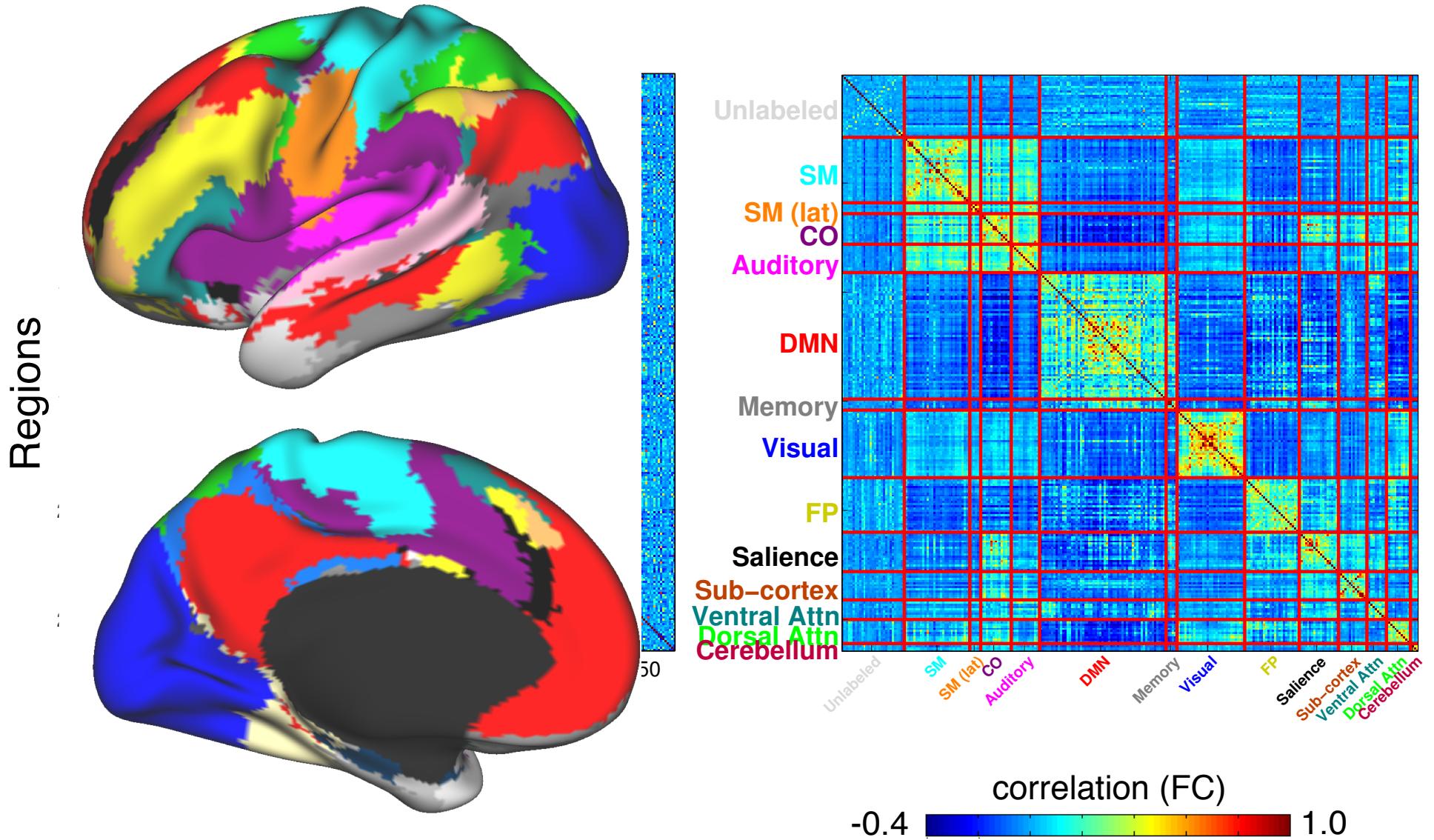
Functional Connectivity (FC): measuring relationships across brain regions



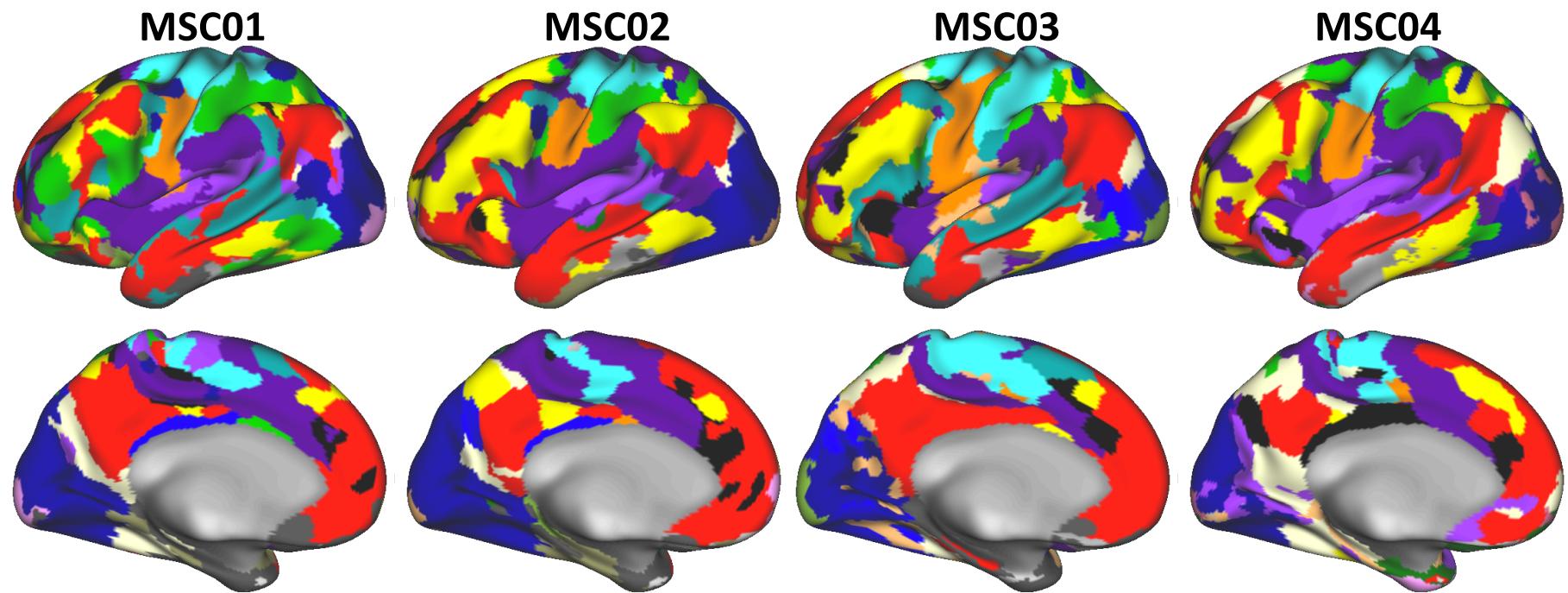
FC: A way to map brain organization



FC: A way to map brain organization



Functional brain networks in individuals



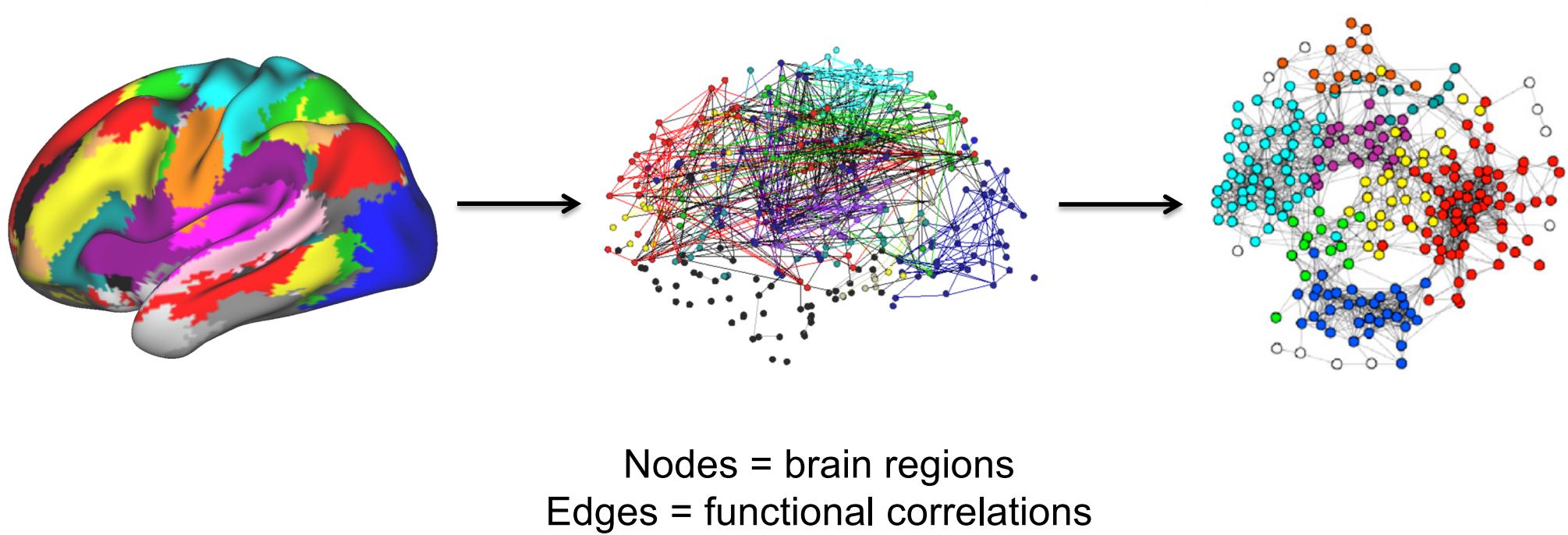
Gordon et al., 2017, Neuron

Braga et al., 2017, Neuron

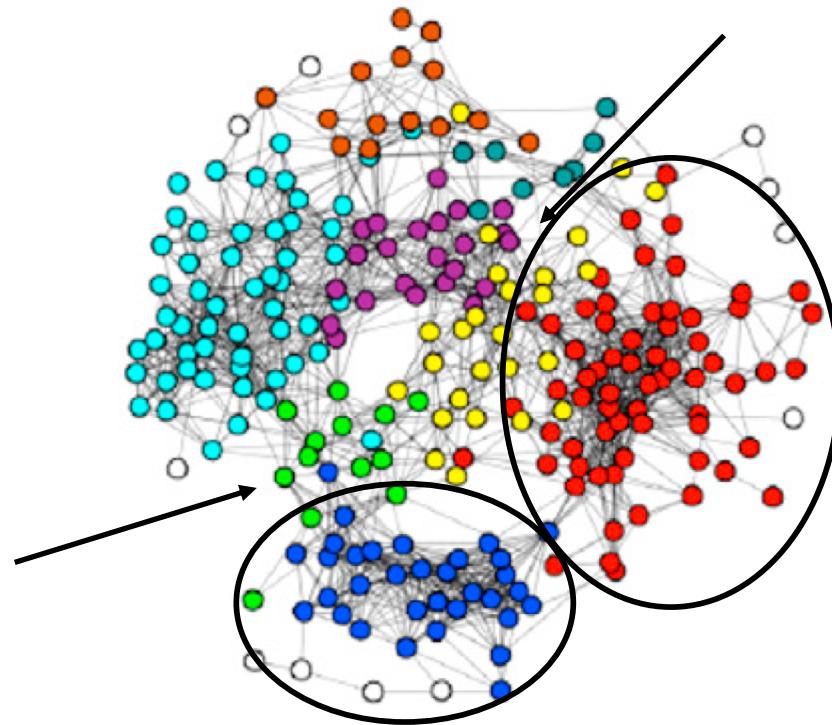
Laumann et al., 2015, Neuron

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**)

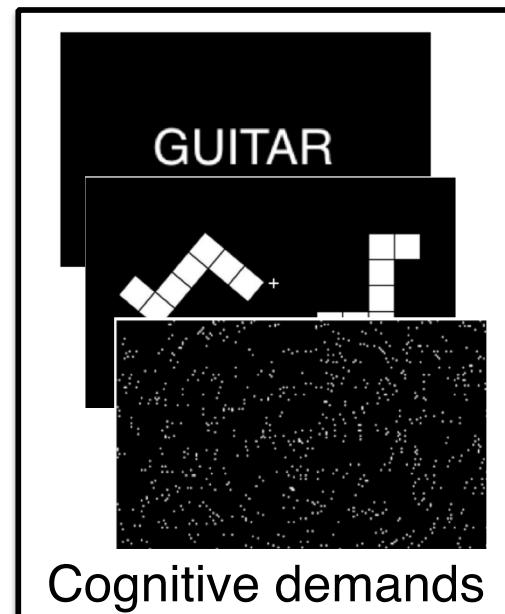
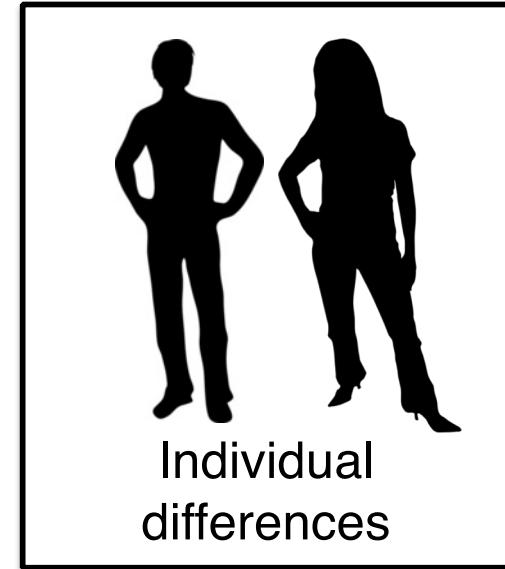
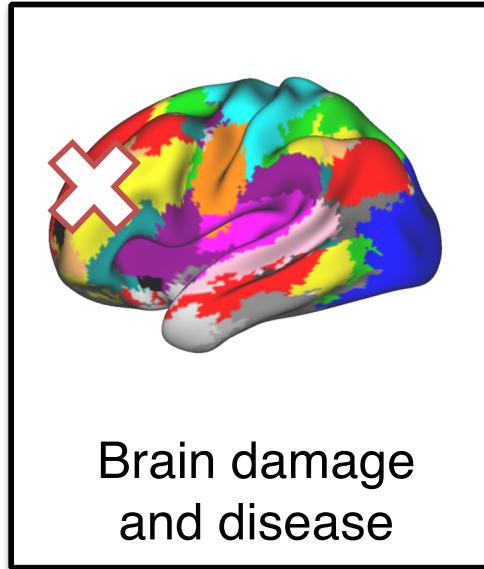
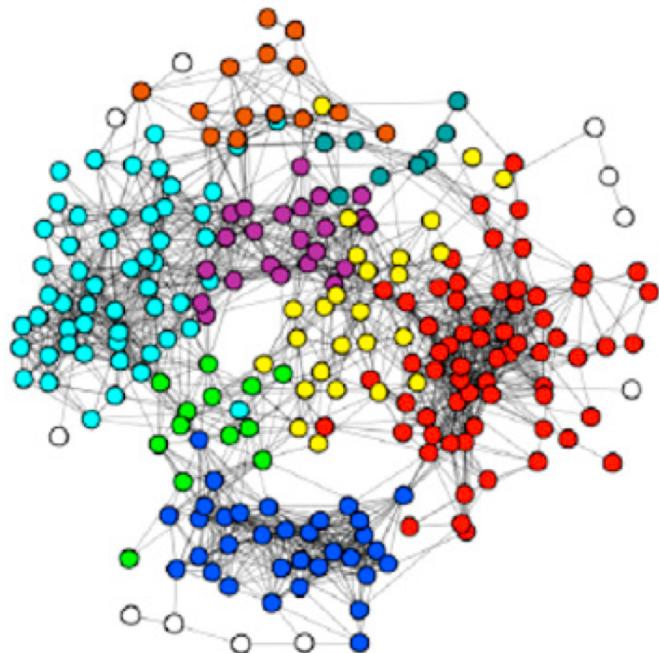
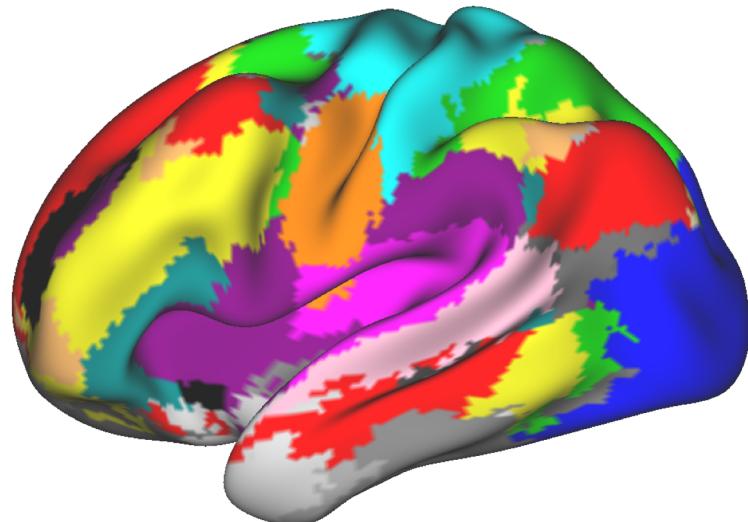
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- 2. Recent work: Forms of variation in functional brain networks**

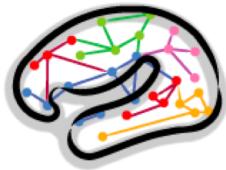
3. Tutorial

The Promise of Functional Connectivity



Paradigms in functional connectivity

Many subject datasets



Human Connectome Project
(Young Adult)
~1200 subjects

HCP Aging: 1200 subjects, age 36-100
HCP Development: 1350 subjects, age 5-21
HCP Baby: 500 subjects, age 0-5
HCP In Utero: 1500 subjects,
20-44 wks post-conception
+ CRHD datasets on human disease



Adolescent Brain Cognitive Development®
Teen Brains. Today's Science. Brighter Future.

biobank^{uk}

ABCD
11878 subjects

UK Biobank
15000 subjects

High-sampling datasets



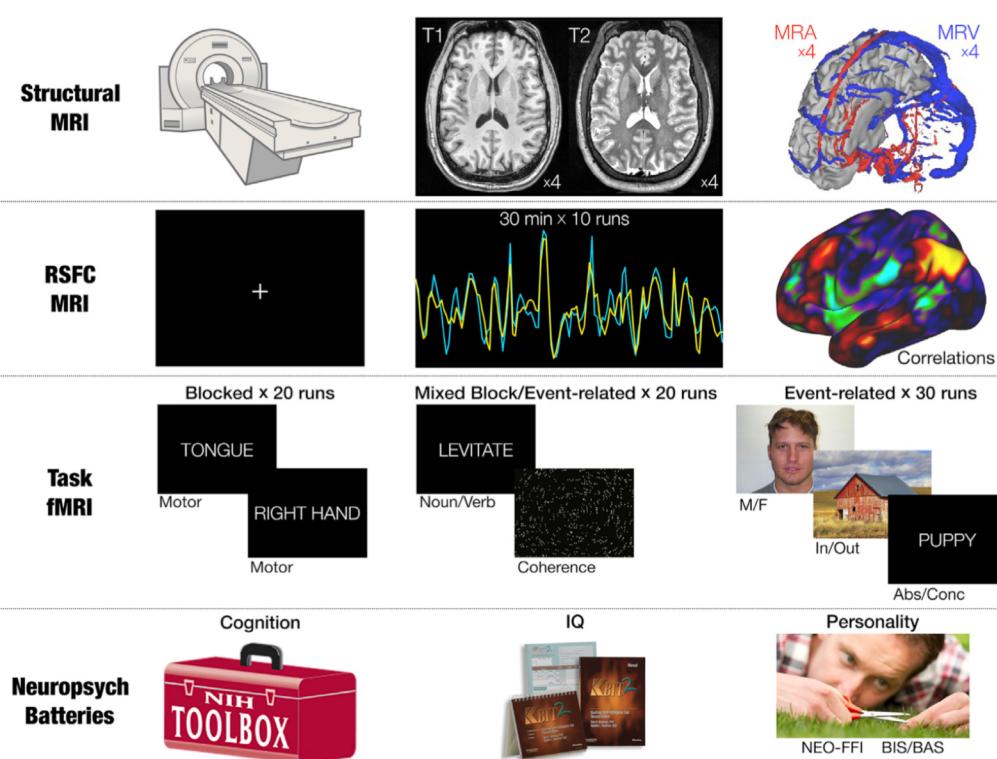
My Connectome
1 participant
80 sessions over 1 yr



Midnight
Scan Club
10 people,
10 sessions

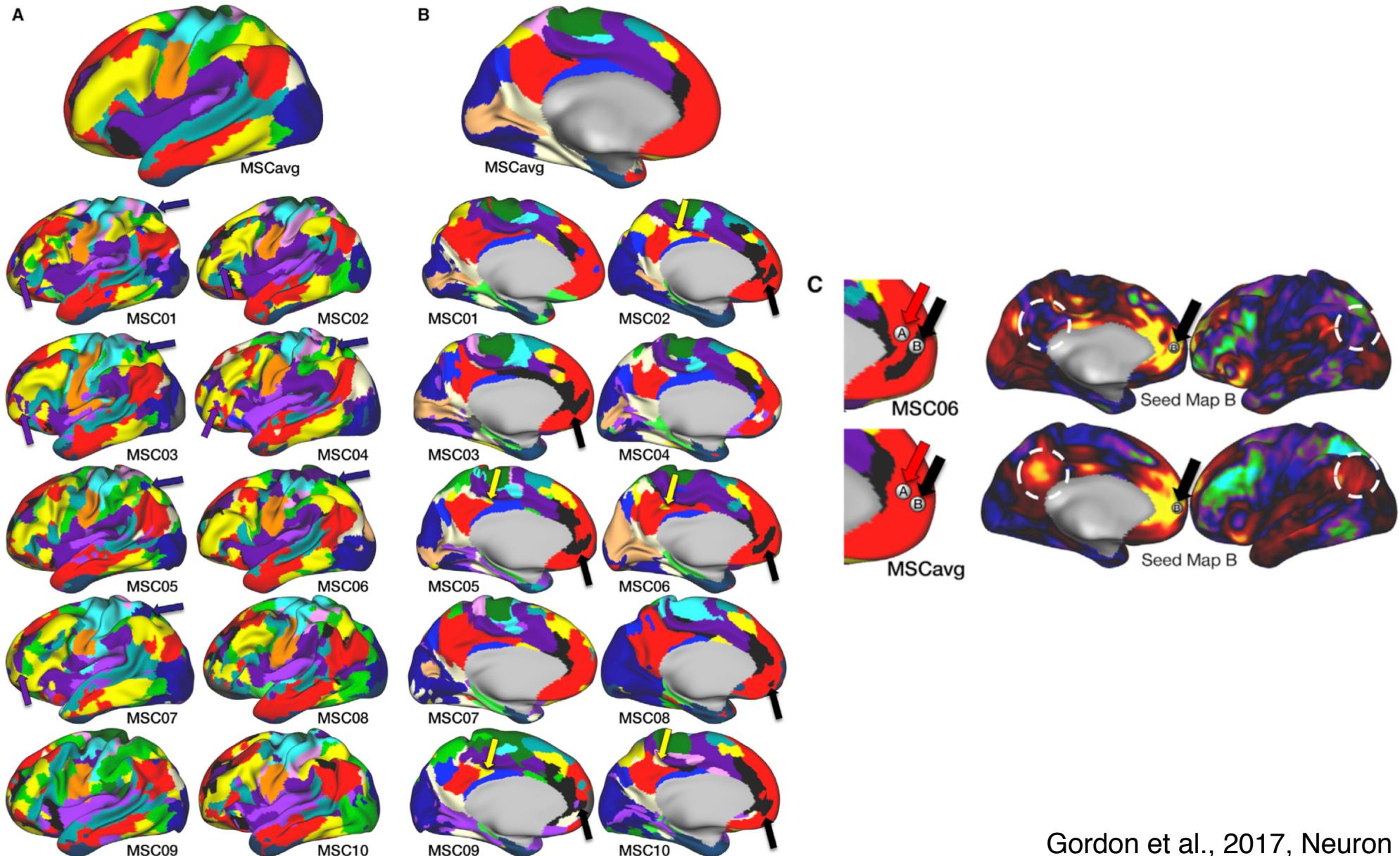
And more, e.g.
Kirby Weekly (N=1, 158 sessions)
Buckner Lab Dataset (N=4, 24 sessions)
Day2Day (N=8, 11-50 sessions)
Healthy Brain Network (N=13, 12 sessions)
Yale Test-Retest (N=12, 4 sessions)

Midnight Scan Club Dataset

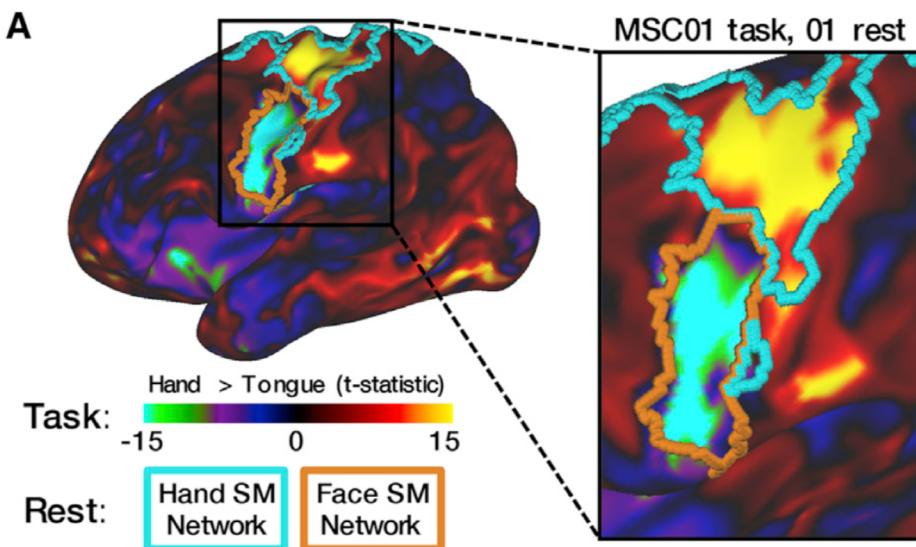
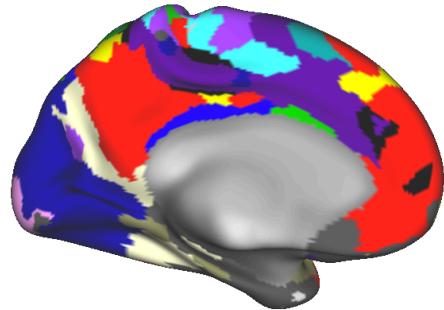
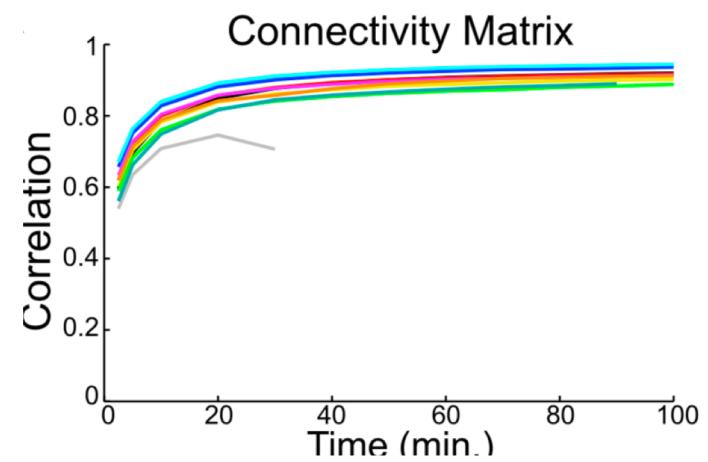
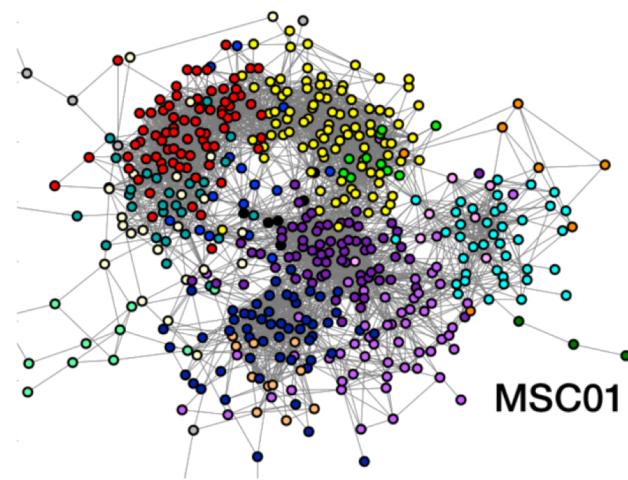
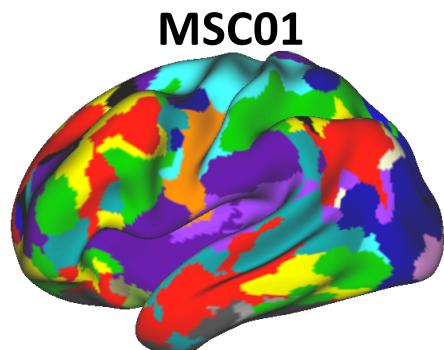


**10 subjects
x 10 sessions
x 3 tasks + rest**

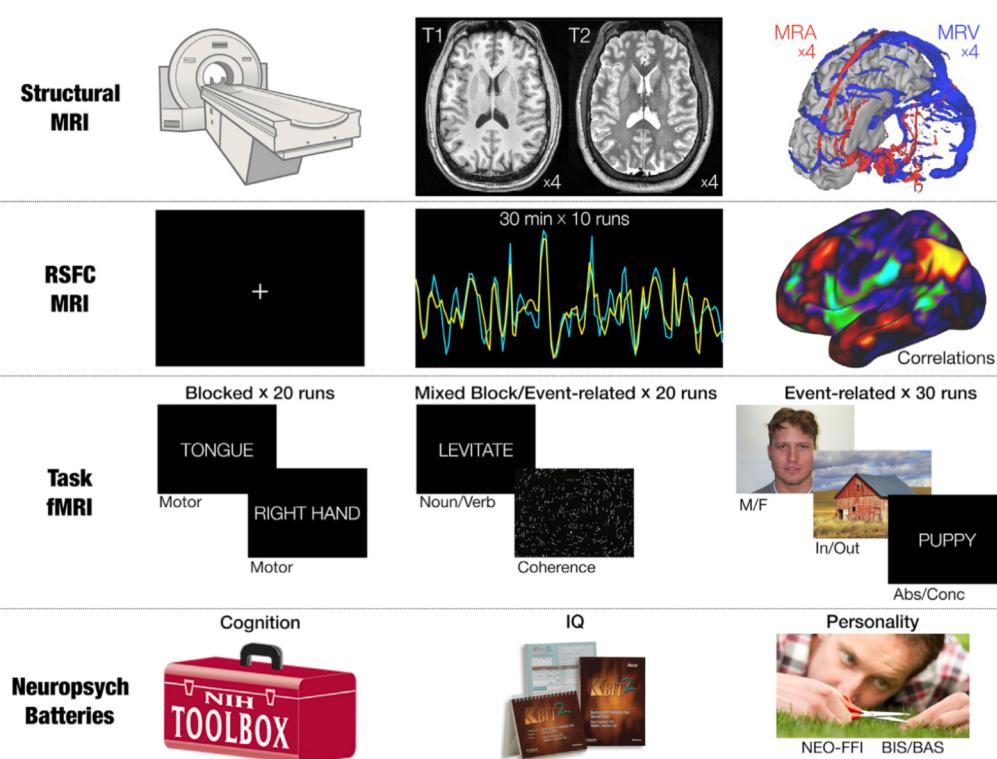
Midnight Scan Club Dataset



Midnight Scan Club Dataset

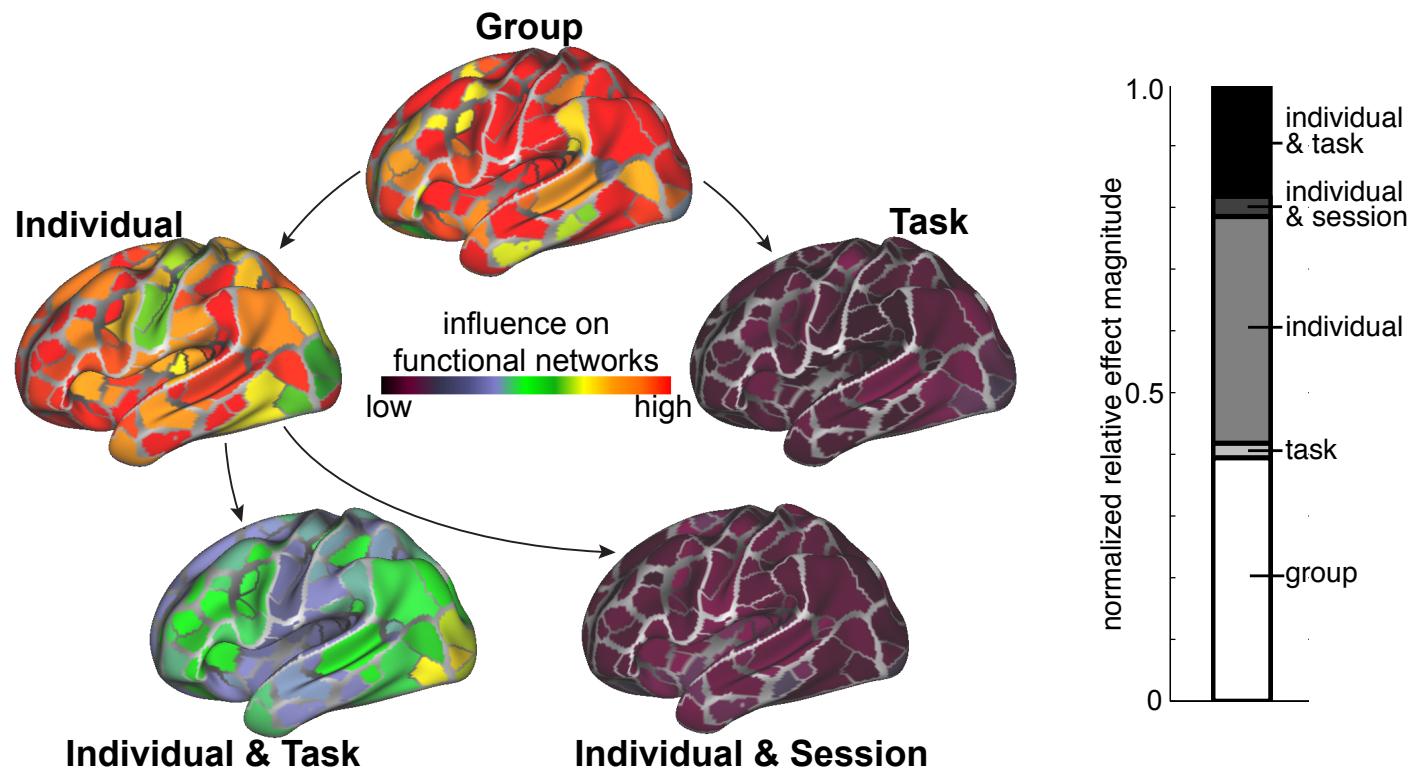


Midnight Scan Club Dataset



**10 subjects
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Midnight Scan Club Dataset



Functional network measures are dominated by stable factors, with smaller contributions from cognitive or daily variation

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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

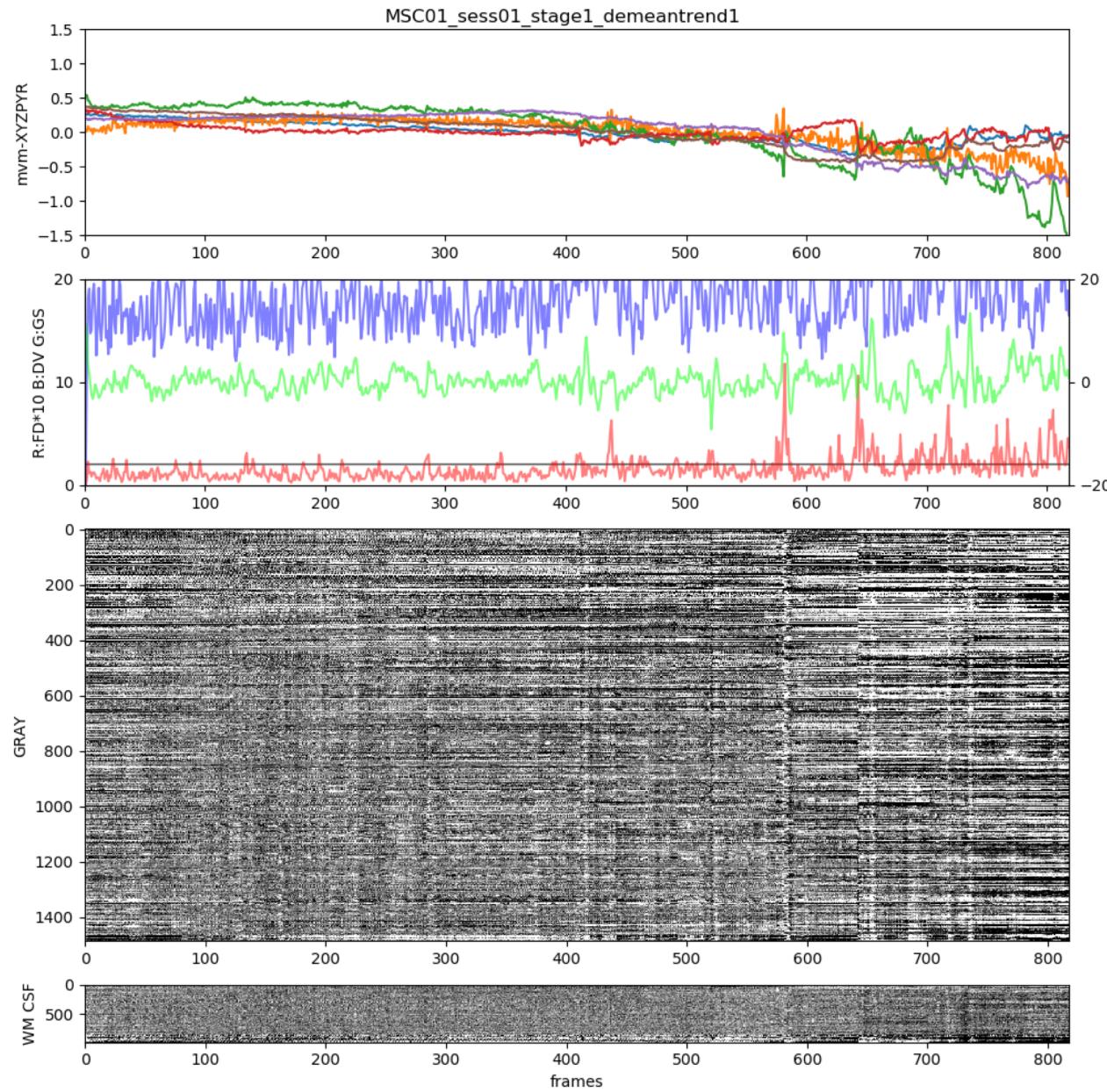
A simple but useful way to assess fMRI scan qualities

Jonathan D. Power

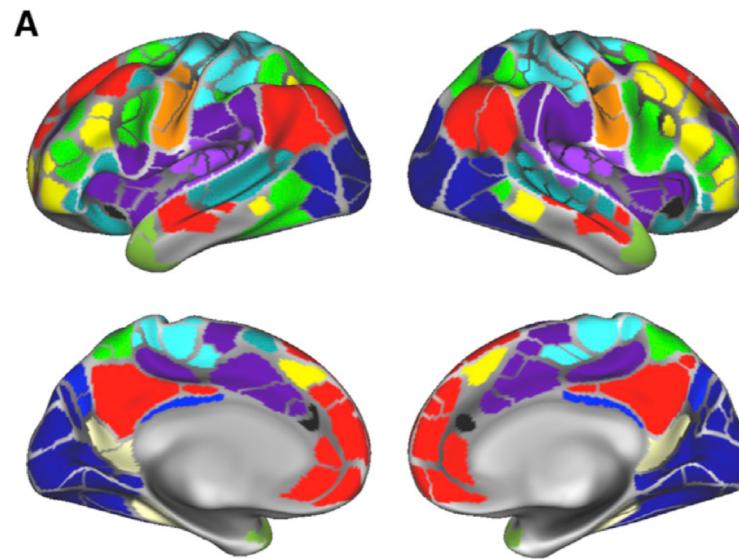
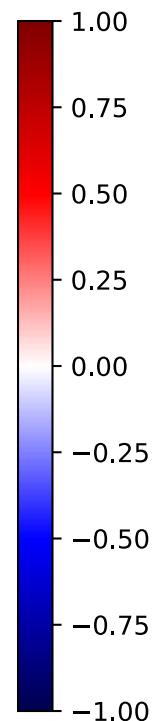
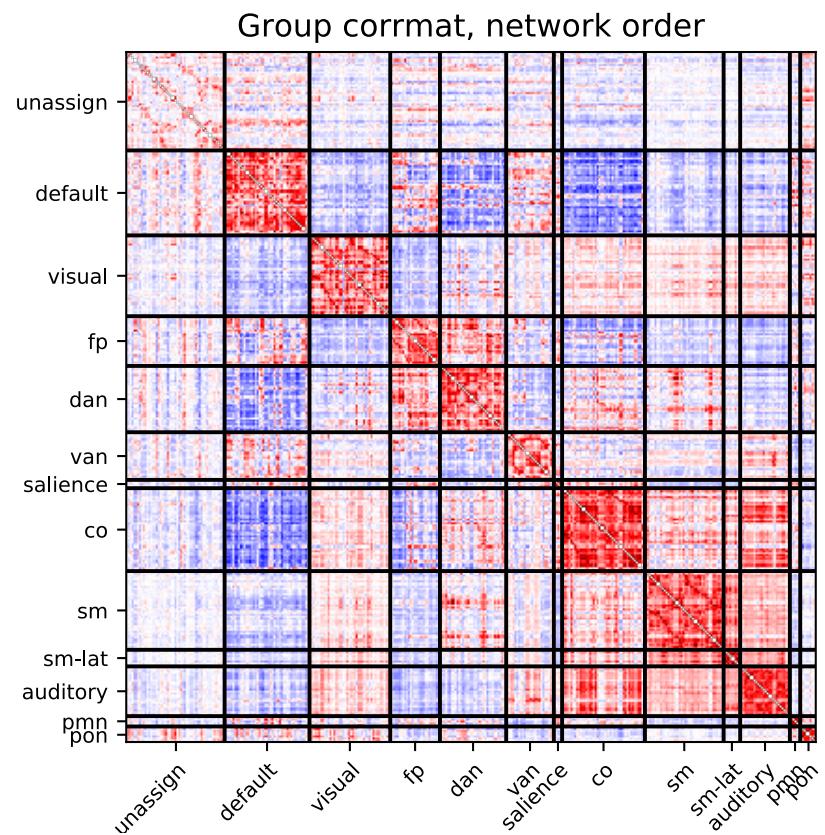
NIMH, National Institute for Mental Health, Building 10 Room 4C104, 10 Center Dr., Bethesda, MD 20814, USA

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

"Grayplots" or "Carpet Plots"



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 Aside: Defining Networks

Physics Reports 486 (2010) 75–174



Contents lists available at [ScienceDirect](#)

Physics Reports

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



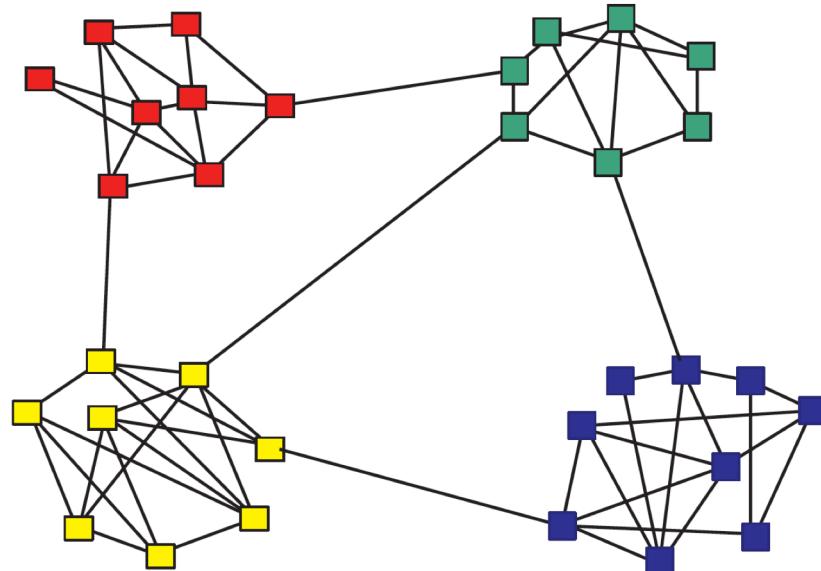
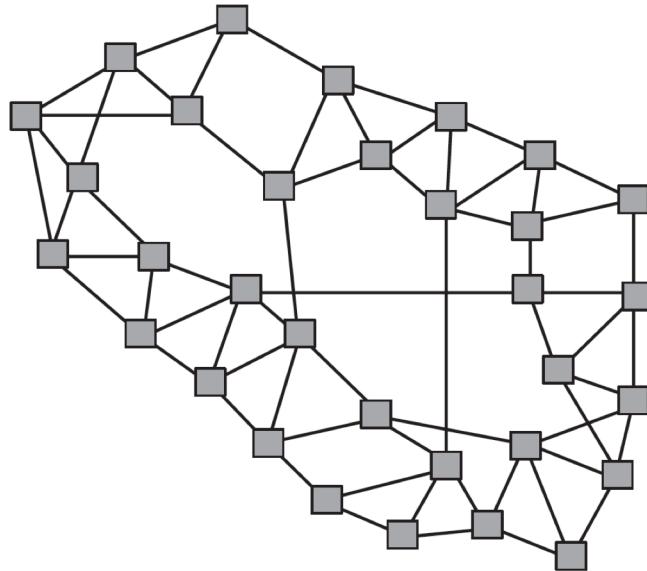
Community detection in graphs

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)

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

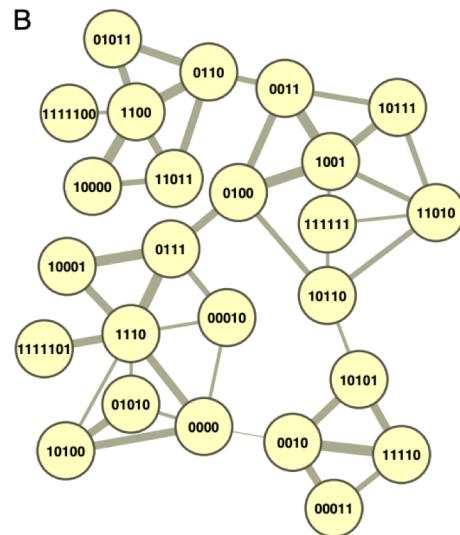
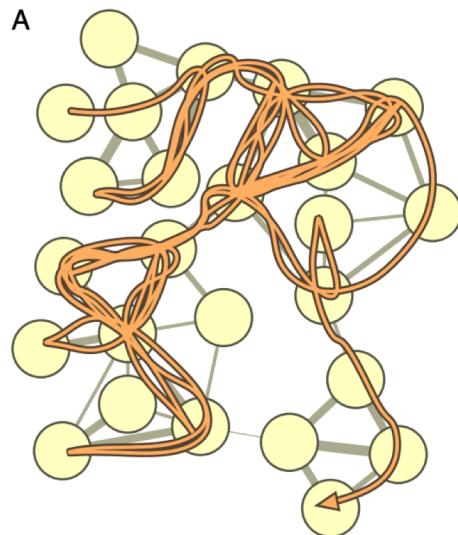
e = fraction of edges within a module
 a = fraction of edges between node in module to any other node

Meunier et al., 2010

Newman & Girvan, 2004

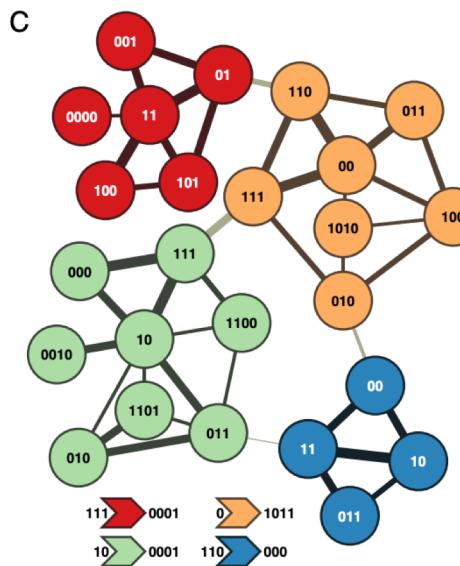
Correlation Matrices Aside: Defining Networks

Infomap



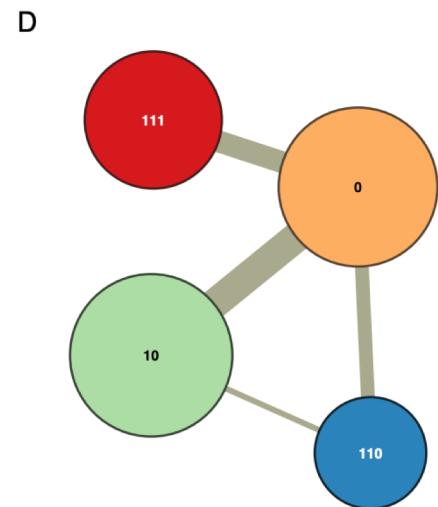
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1001 0100 0111 10001 1110 0111 10001 0111 1110 0000 1110 10001 0111
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0100 10110 11010 11011 1001 0100 10111 01001 1001 0100 10111 01001
0011 0100 0011 0110 11011 0110 0011 0100 1001 10111 0011 0100 10111
0111 10001 110 0111 1001 1110 0011 0100 10111 0011 0100 10111 0011
0111 1000 10 111 000 111 10 011 10 000 111 10 111 10 000 10 10 011 010
011 10 000 111 0001 0 111 010 100 011 00 111 00 011 00 111 00 111 00
110 111 110 101 111 01 101 01 0001 0 111 010 1010 010 1011 110 00 10 011
10 111 000 10 000 111 0001 0 111 010 1010 010 1011 110 00 10 011 110 111 1011

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

243 bits

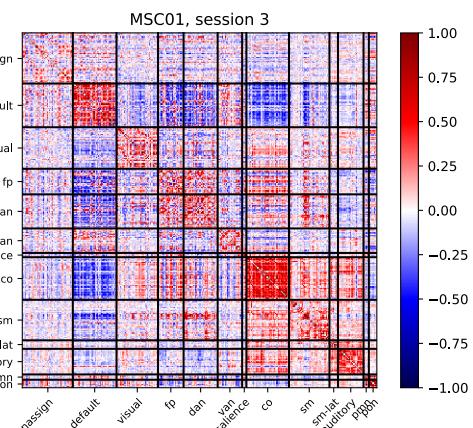
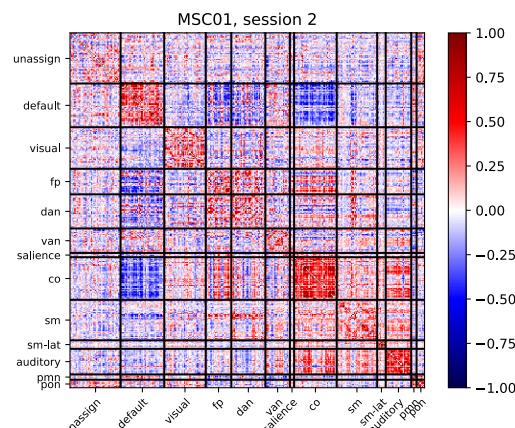
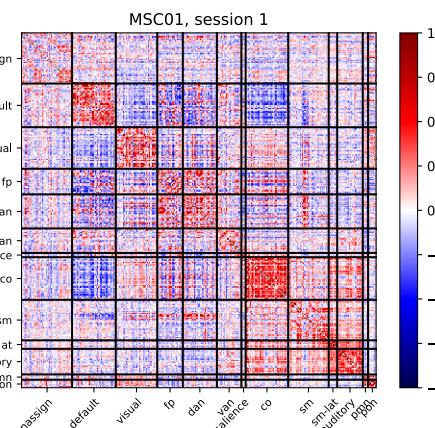
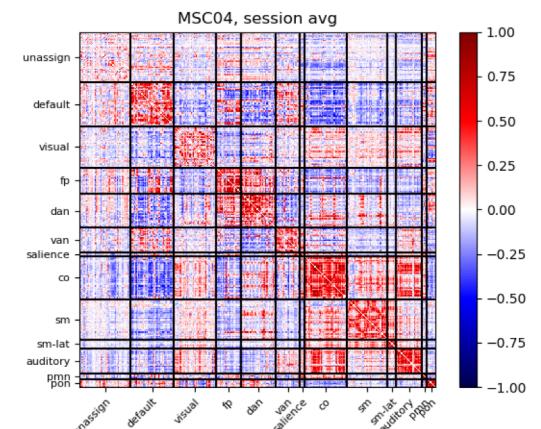
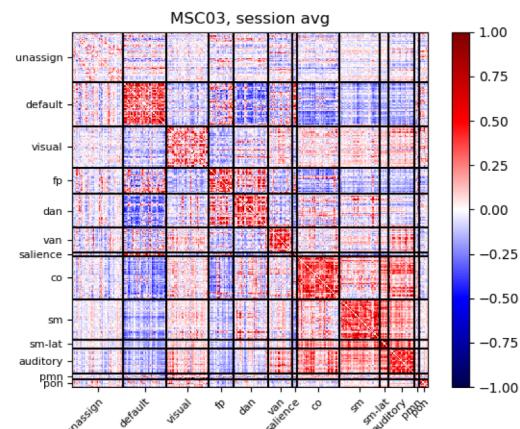
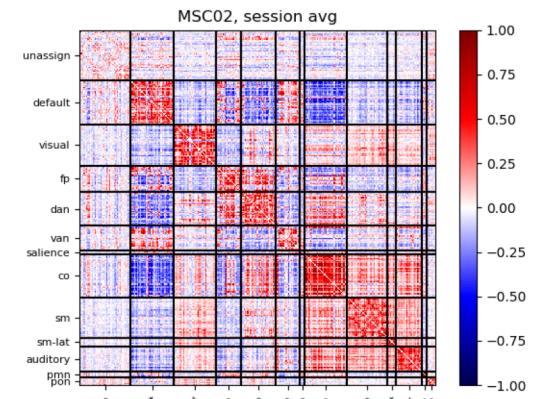
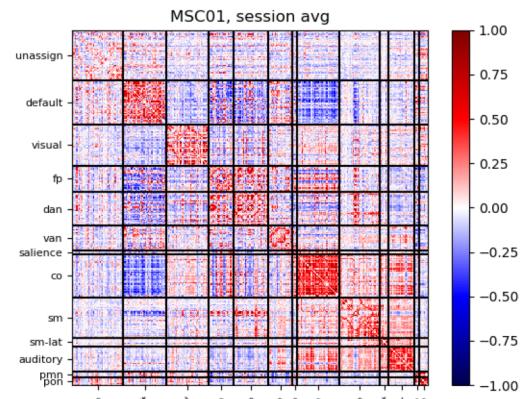
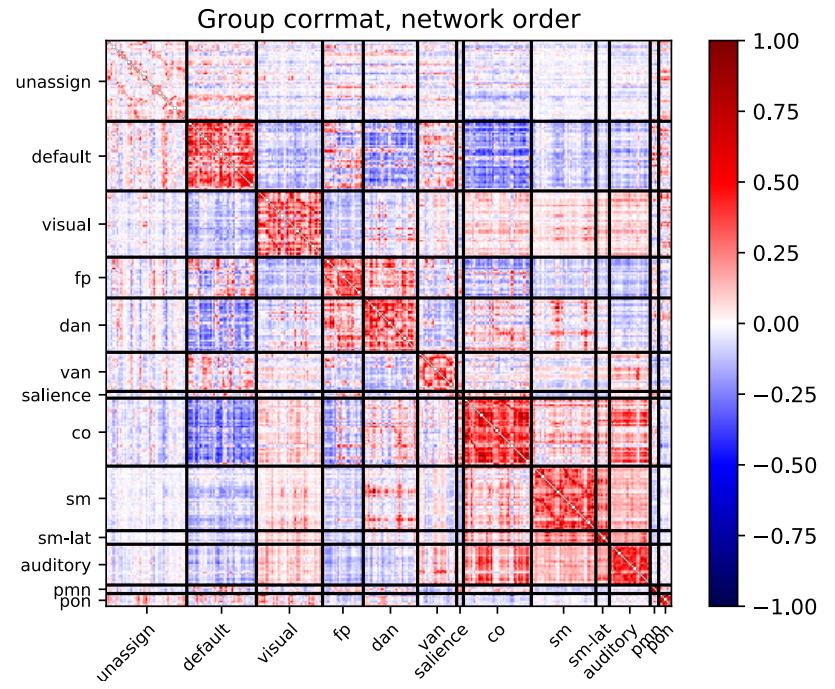


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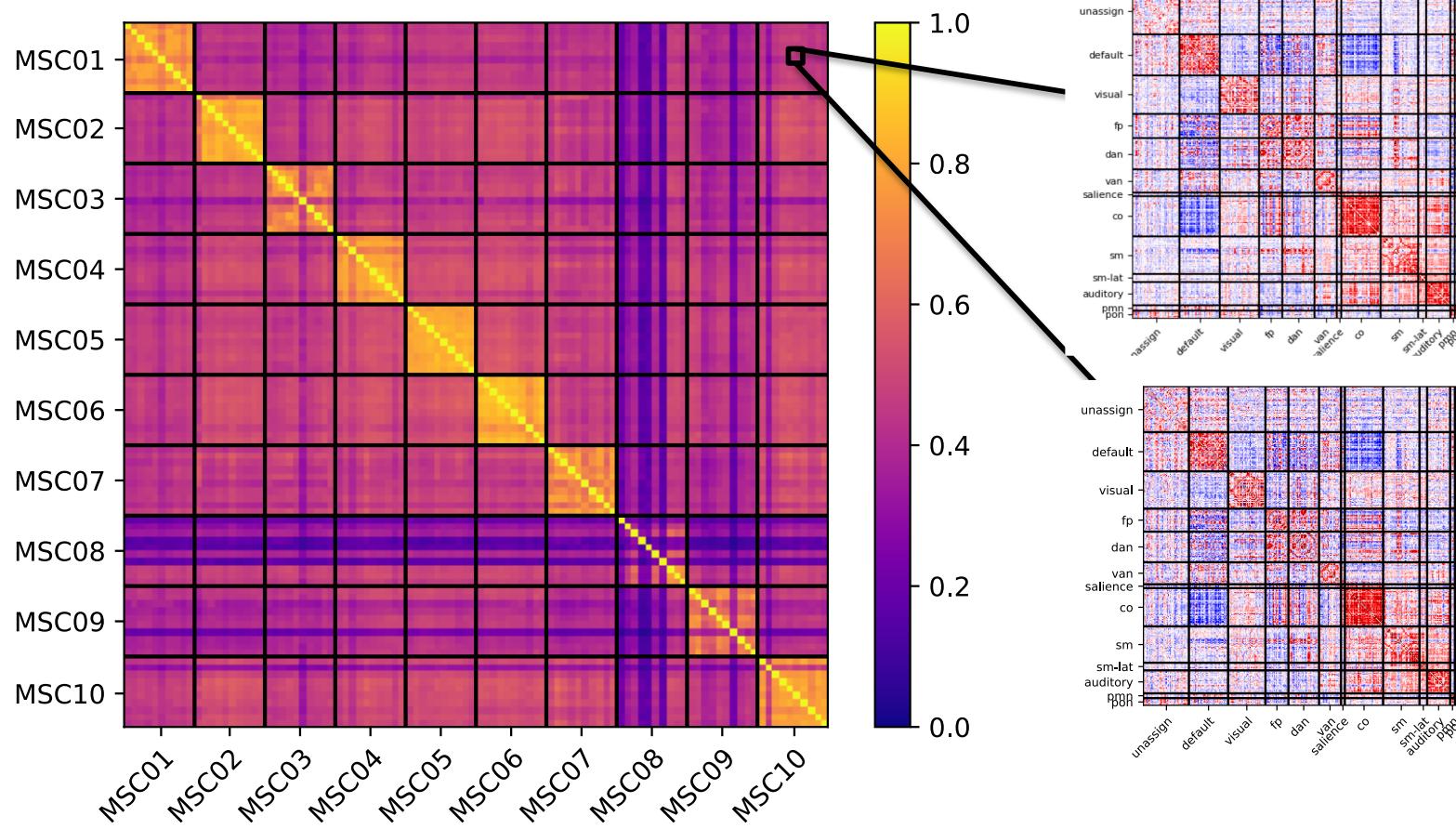
<https://www.mapequation.org/>

Rosvall & Bergstrom, 2008, PNAS

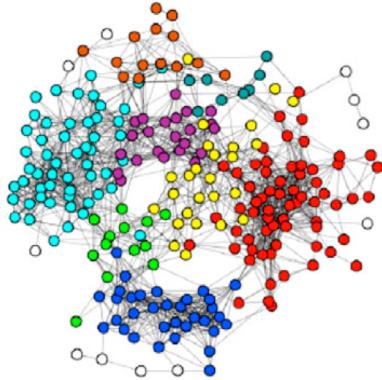
Correlation Matrices



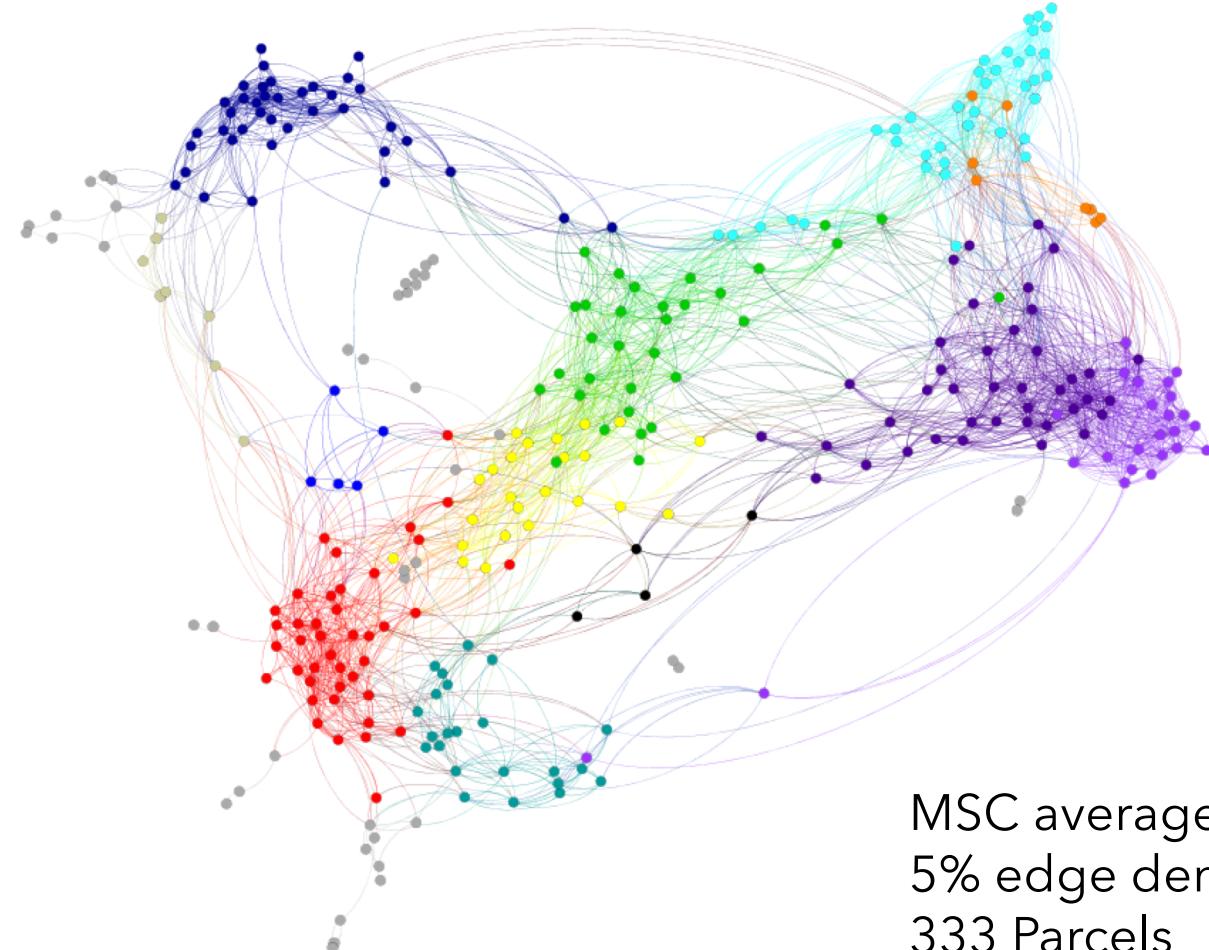
Correlation Matrices - Similarity



Graphs of Brain Networks

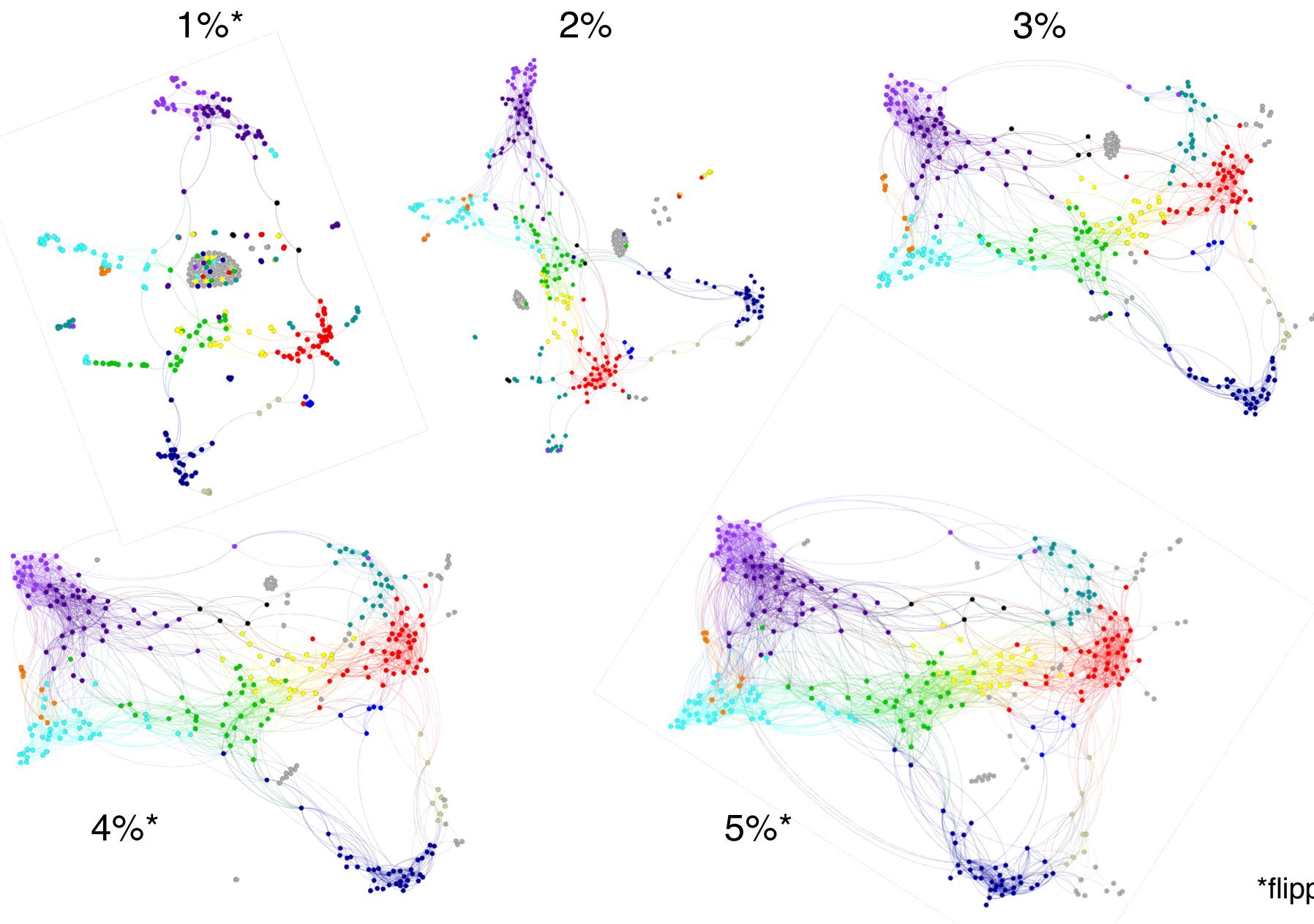


Power et al., 2014
120 person average
264 Power regions

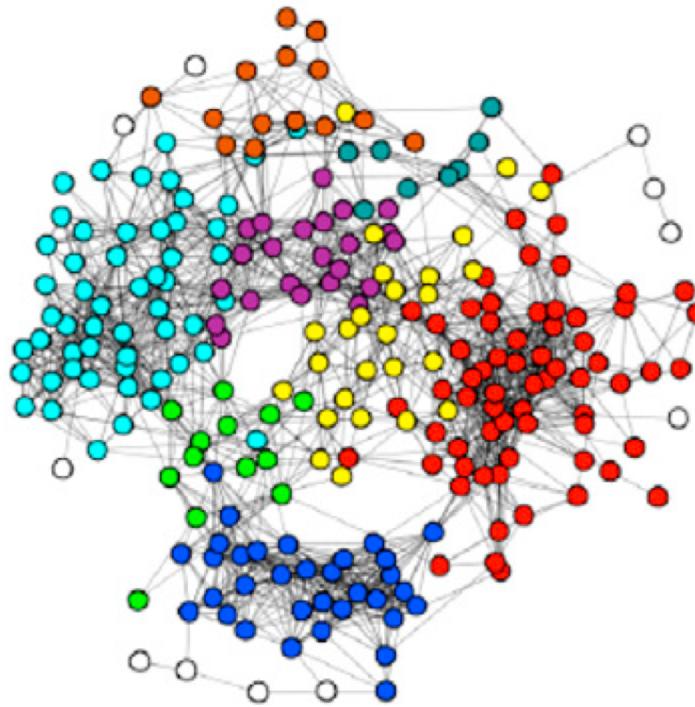


MSC average
5% edge density
333 Parcels
Gephi Force Layout

Graphs of Brain Networks



Hub Measures

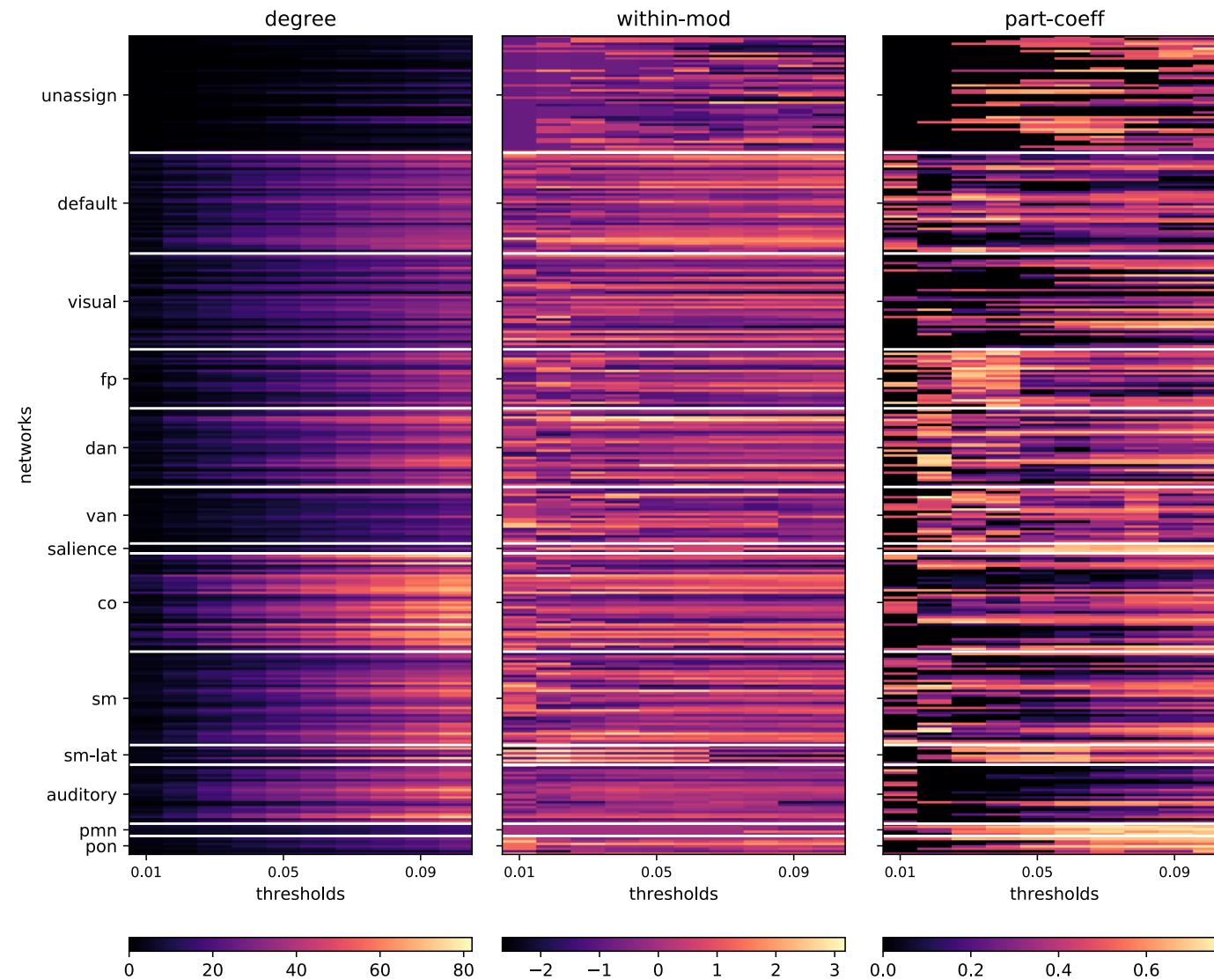


Degree: number of connections to a node

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

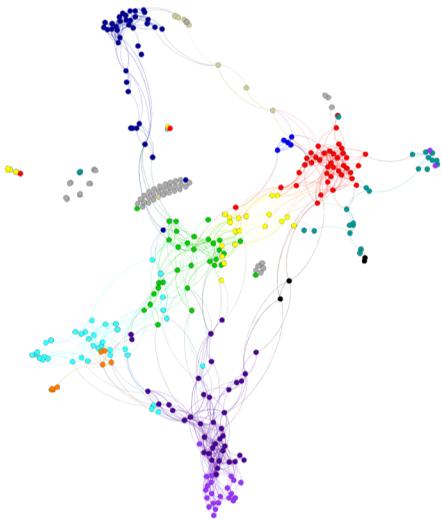
Participation coefficient: distribution of a node's connections across modules

Hub Measures

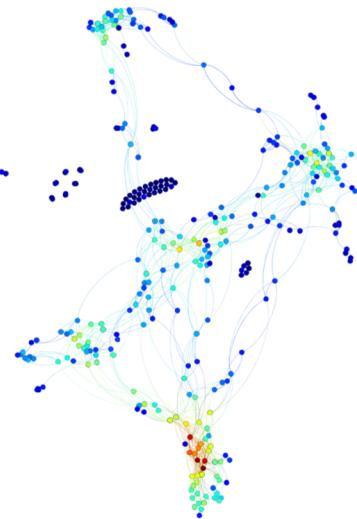


Hub Measures

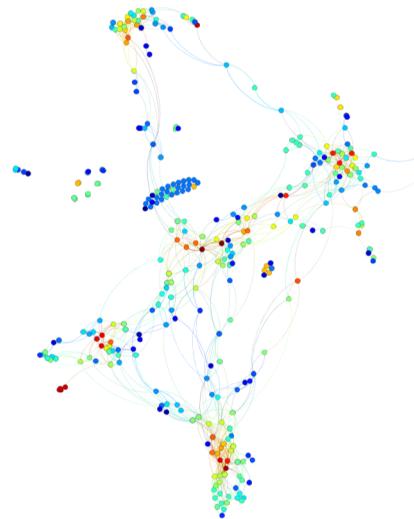
network



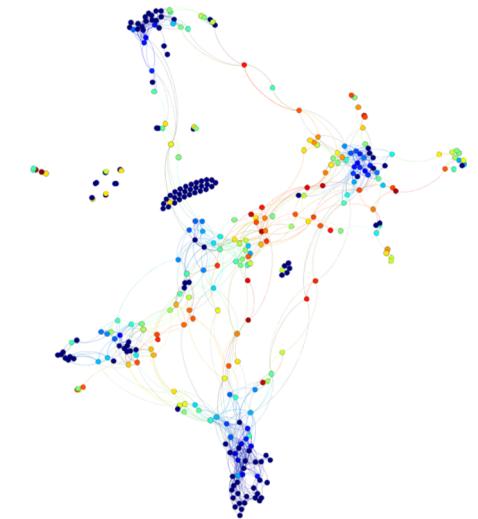
degree



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

Acknowledgments

Gratton Lab

Brian Kraus

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Ben Seitzman

Joe Dubis

Becky Coalson

Fran Miezin

Mark McAvoy

Ally Dworetzky

MSC:

Nico Dosenbach

Steve Nelson

Deanna Greene

Adrian Gilmore

Jeff Berg

Dillan Newbold

Mario Ortega

Catherine Hoyt Drazen

Jacqueline Hampton

Annie Nguyen

Scott Marek

Kathleen McDermott



Questions?

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grattonlab.org



Neurological Disorders
and Stroke



McDONNELL CENTER FOR
DCSN SYSTEMS
NEUROSCIENCE
National Center
for Advancing
Translational Sciences

Thank You!