

CONNECTOME ANALYSIS IN EPILEPSY

BORIS BERNHARDT, PHD

MONTREAL NEUROLOGICAL INSTITUTE

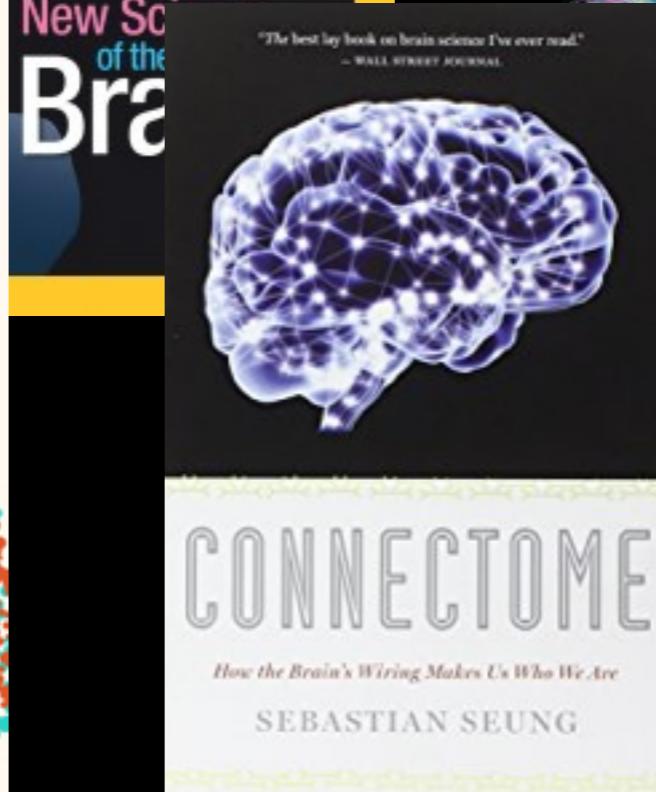
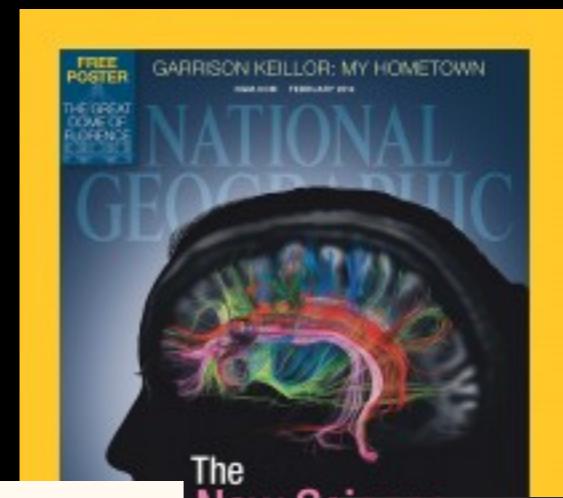
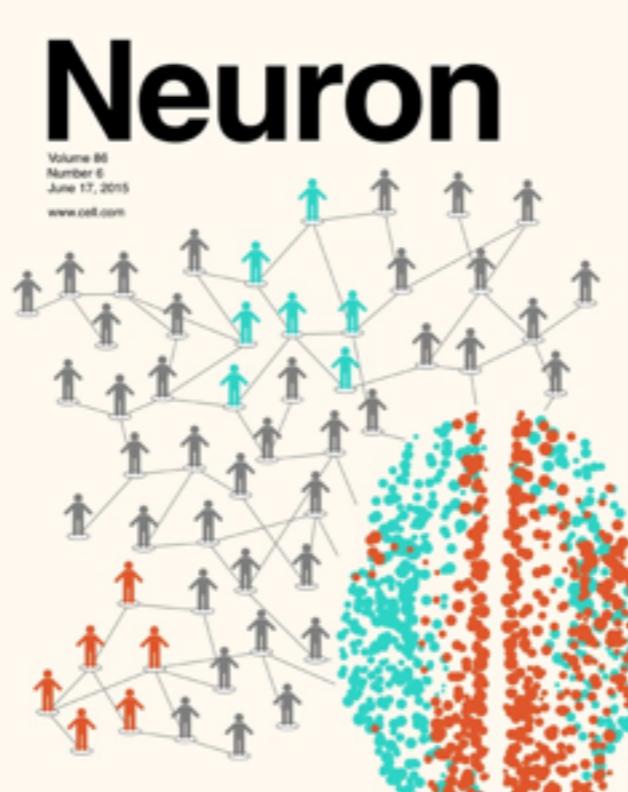
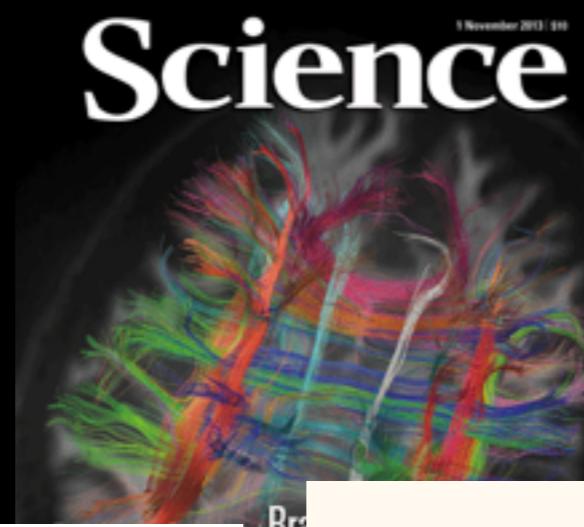
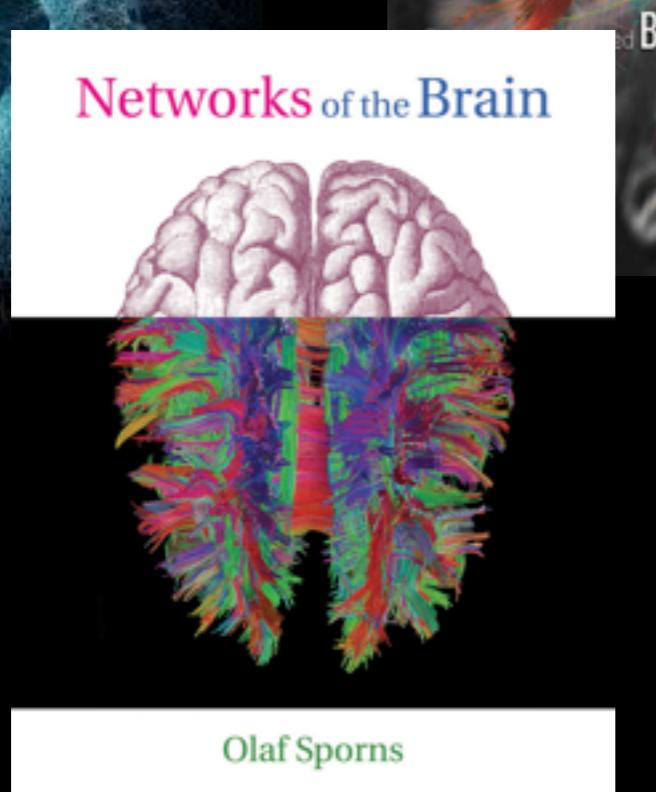
MCGILL UNIVERSITY

lab: <http://mica-mni.github.io>

twitter: @BorisBernhardt



WHY STUDY CONNECTIVITY?



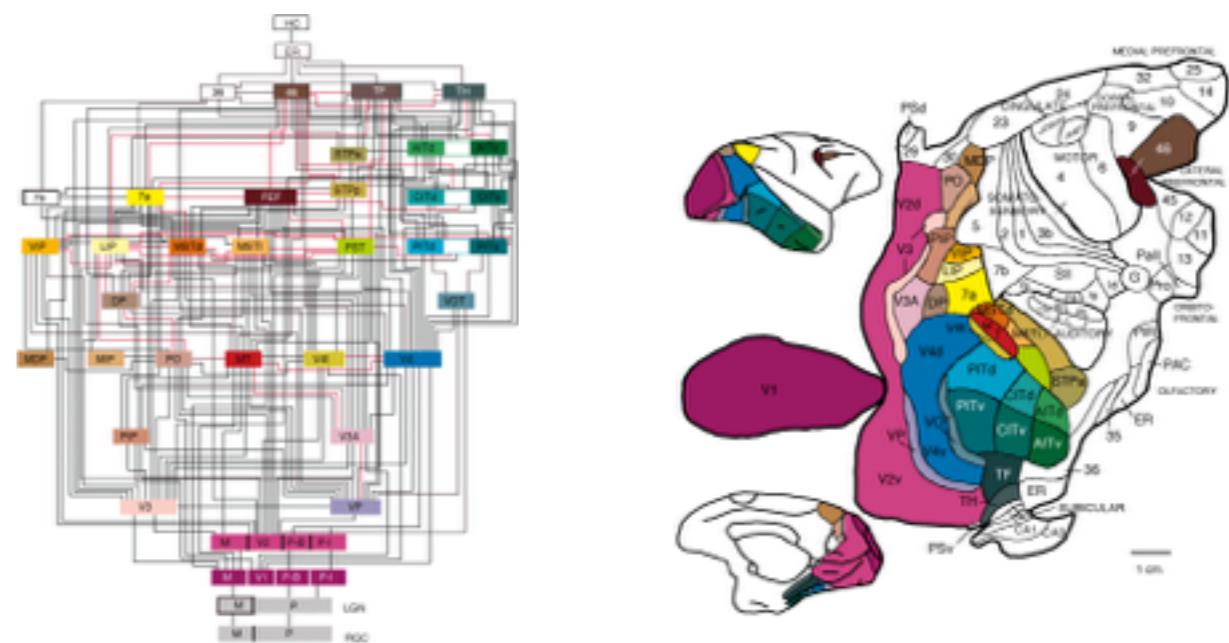
HOW TO MEASURE BRAIN CONNECTIVITY?

(ANIMAL) CONNECTIVITY

ANATOMICAL CONNECTIONS:
THE WIRING BETWEEN REGIONS

CLASSICALLY DERIVED FROM
TRACT-TRACER STUDIES

INVASIVE, CAN ONLY BE
PERFORMED IN ANIMALS



Stephan and Koetter, 2000, CoCoMac

HUMAN IN-VIVO CONNECTIVITY

MRI KEY MODALITY
TO APPROXIMATE BRAIN CONNECTIVITY

NON-INVASIVE

HIGH-RESOLUTION

WHOLE-BRAIN

3-DIMENSIONAL

FUNCTIONAL & STRUCTAL CONNECTIVITY



DIFFUSION MRI CONNECTIVITY

IDEA:
FOLLOW PATHWAYS
OF UNHINDERED WATER DIFFUSION

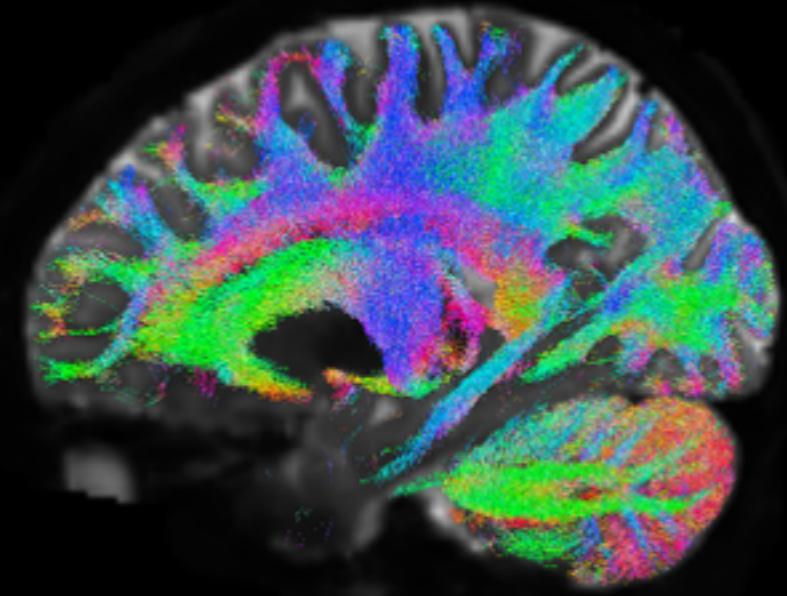
+
PROBES
WM CONNECTIVITY

DIFFUSION PARAMETER
ANALYSIS CAN BE PERFORMED AS WELL

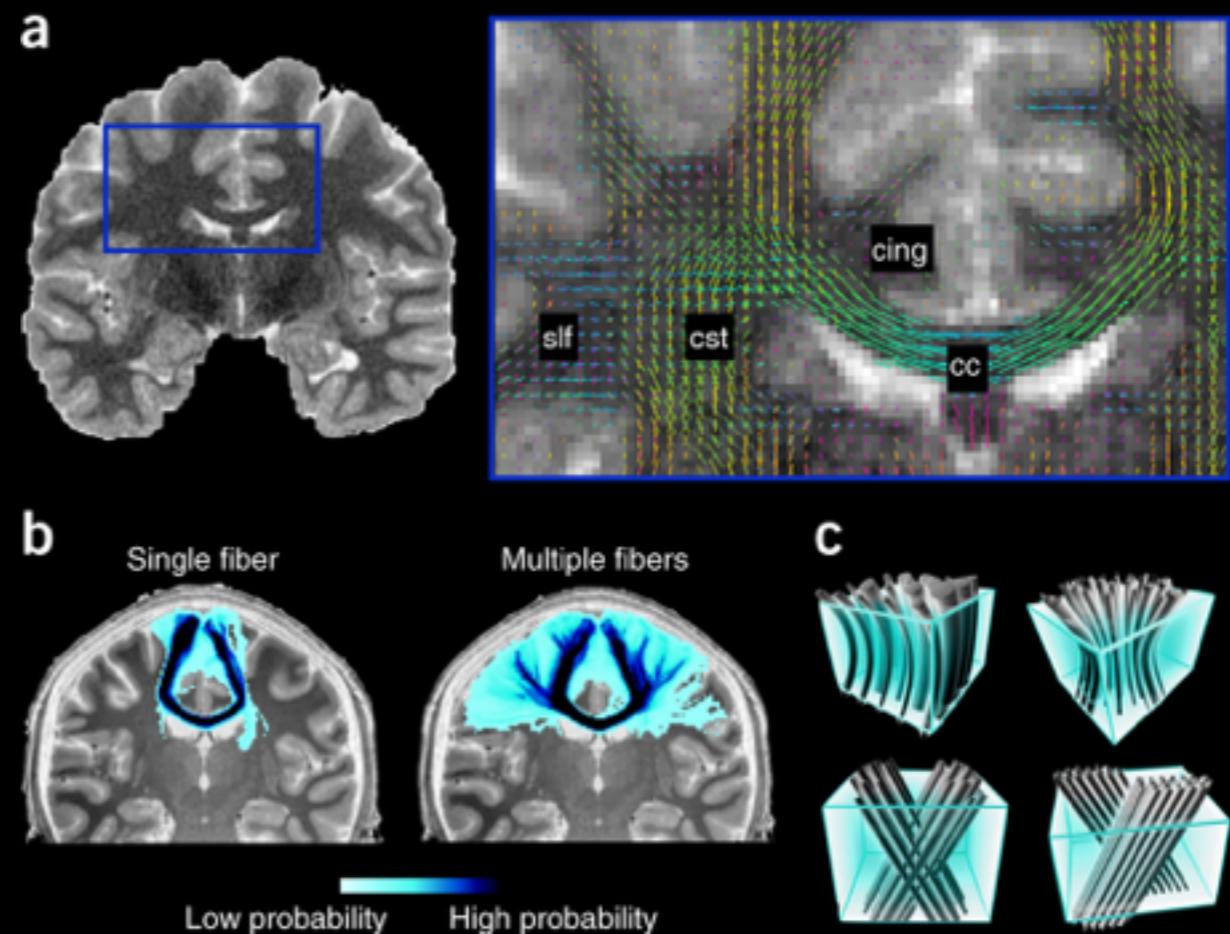
-
CHALLENGES IN REGIONS OF
FIBRE CROSSING AND UNCERTAINTY

DISTANCE BIAS

VALIDITY IN PATHOLOGICAL
REGION UNCLEAR



SINGLE SUBJECT (HCP)



RESTING-STATE fMRI CONNECTIVITY

IDEA:
CORRELATE SPONTANEOUS BRAIN
ACTIVITY

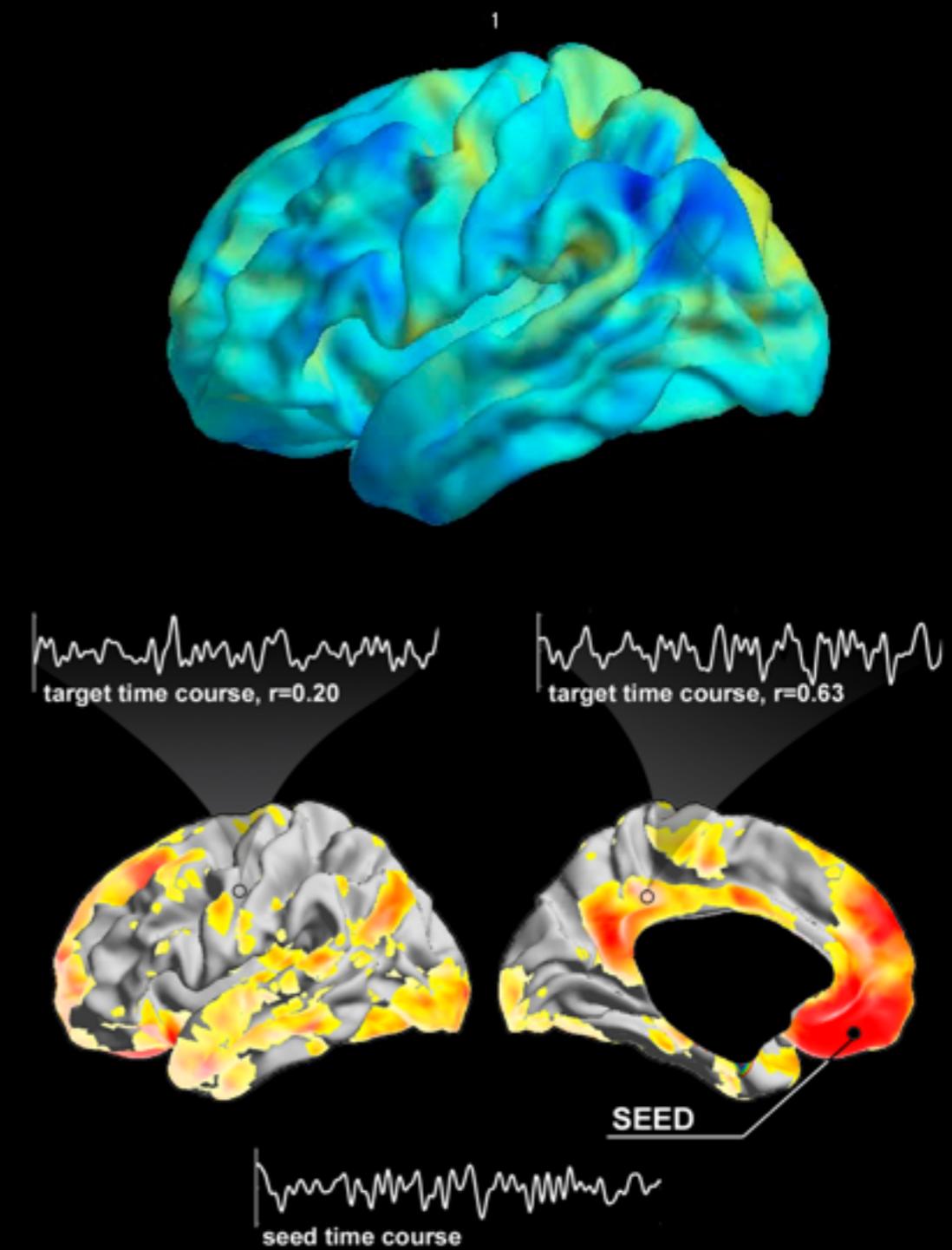
+
COST-EFFECTIVE, REPRODUCIBLE

INDIVIDUALIZED
REGIONAL AND INTER-REGIONAL

SEEDING FROM GM
CORRELATION WITH MENTAL STATES
& INDUCTION

-
EFFECTS OF PHYSIOLOGY + MOTION
INDIRECT CONNECTIONS

CORRELATION WITH MENTAL STATES
& INDUCTION



MRI COVARIANCE ANALYSIS

IDEA:
CORRELATE MORPHOLOGICAL
INDICES ACROSS SUBJECTS

+
COST-EFFECTIVE, REPRODUCIBLE

DIRECT SEEDING FROM GREY
MATTER POSSIBLE

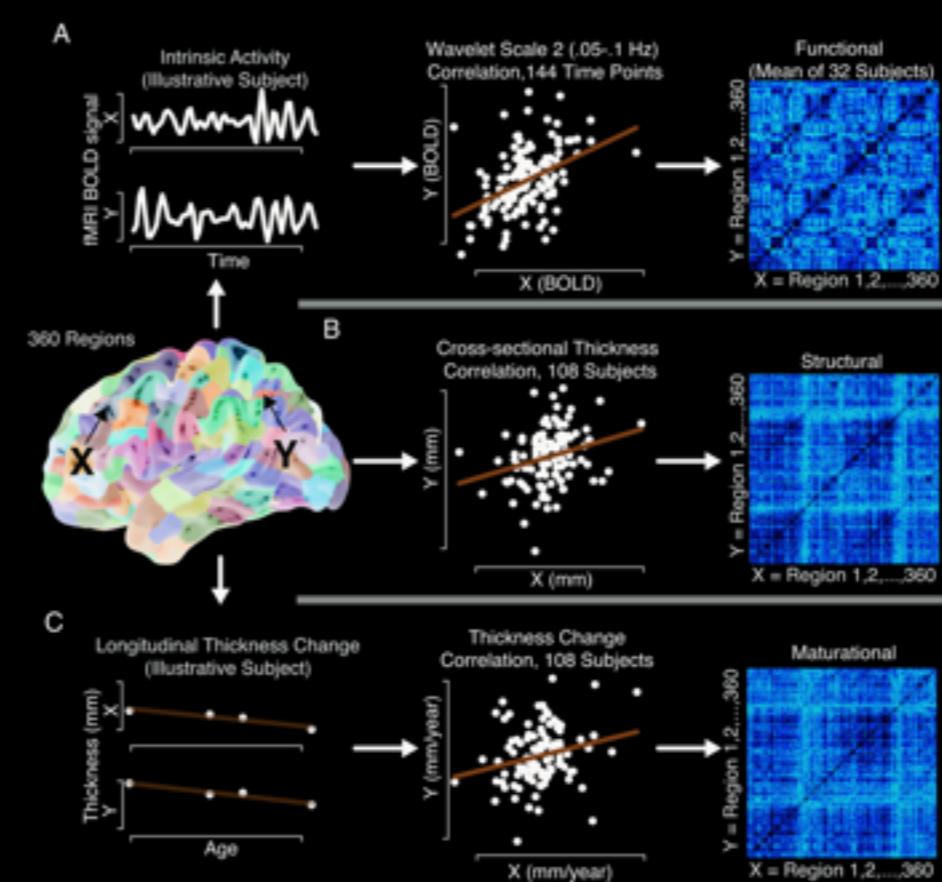
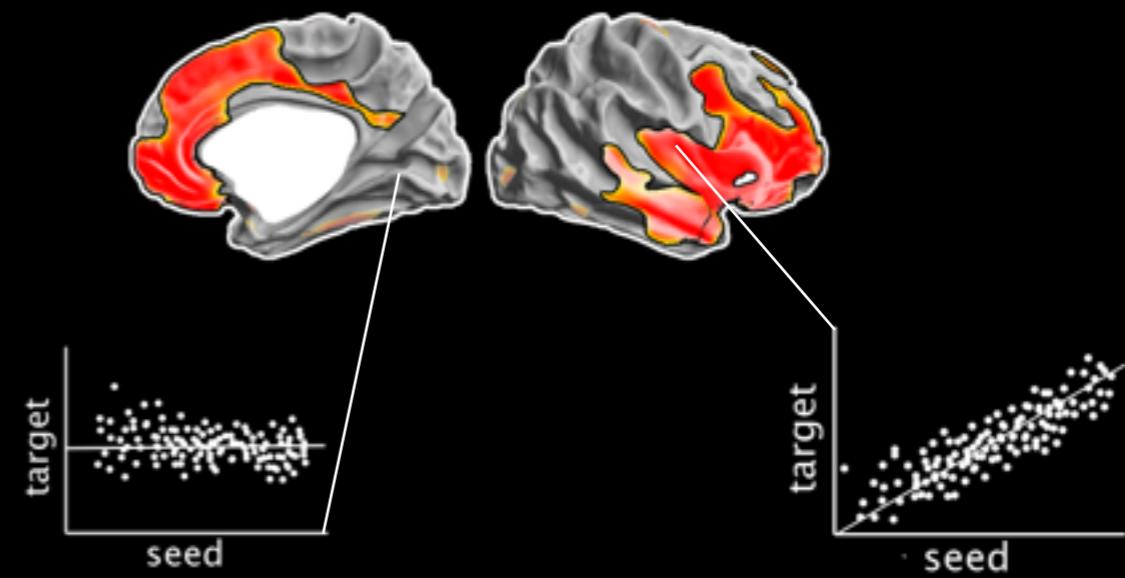
SIMPLE PREPROCESSING AND MODELLING

-

ONLY GROUP-WISE

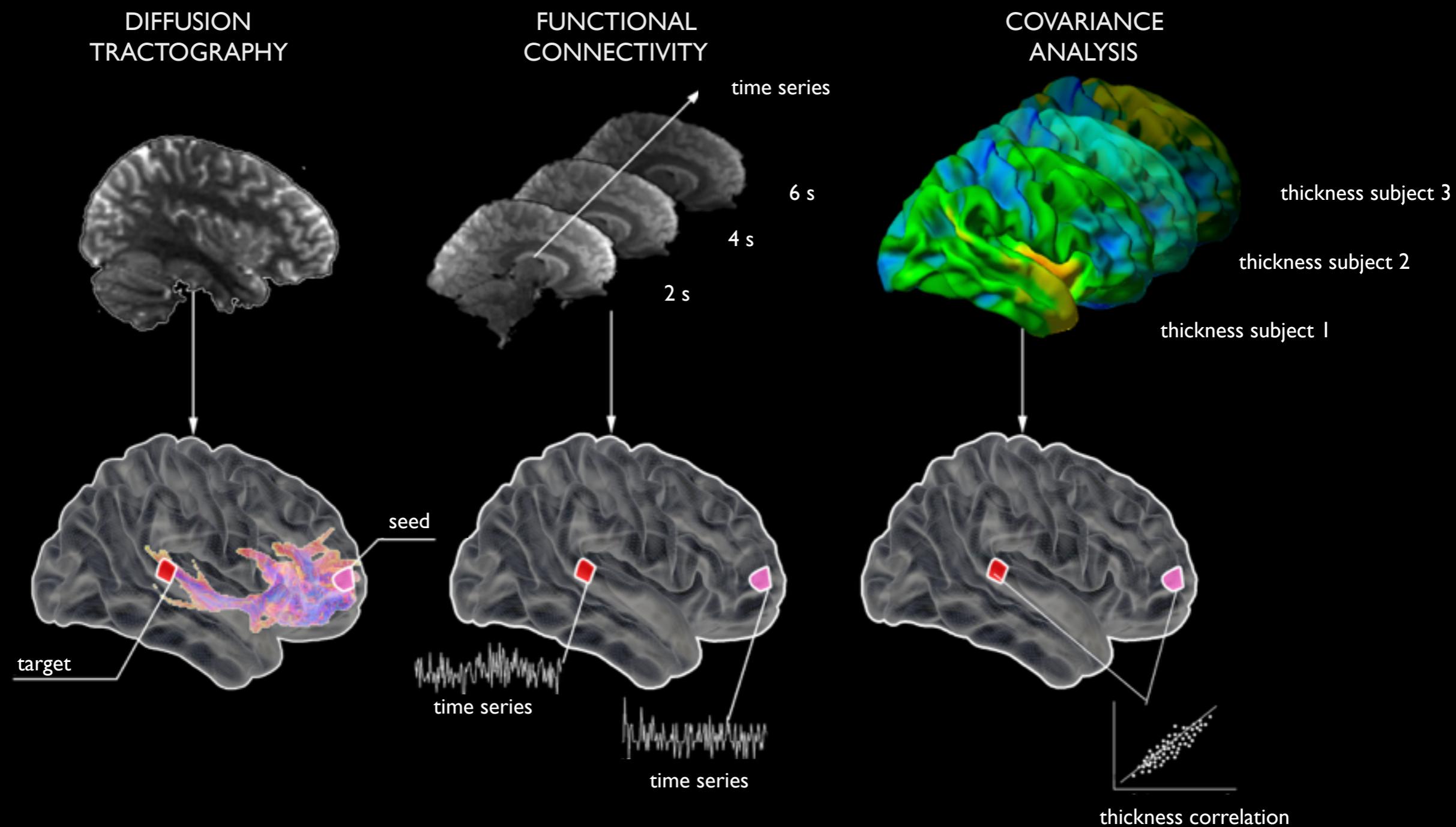
RELATES RATHER TO PROCESSES
THAN TO STATES

NO DIRECT WM CONNECTIVITY
MEASUREMENT



HOW TO GENERATE CONNECTOMES

INTER-REGIONAL CONNECTIVITY ANALYSIS

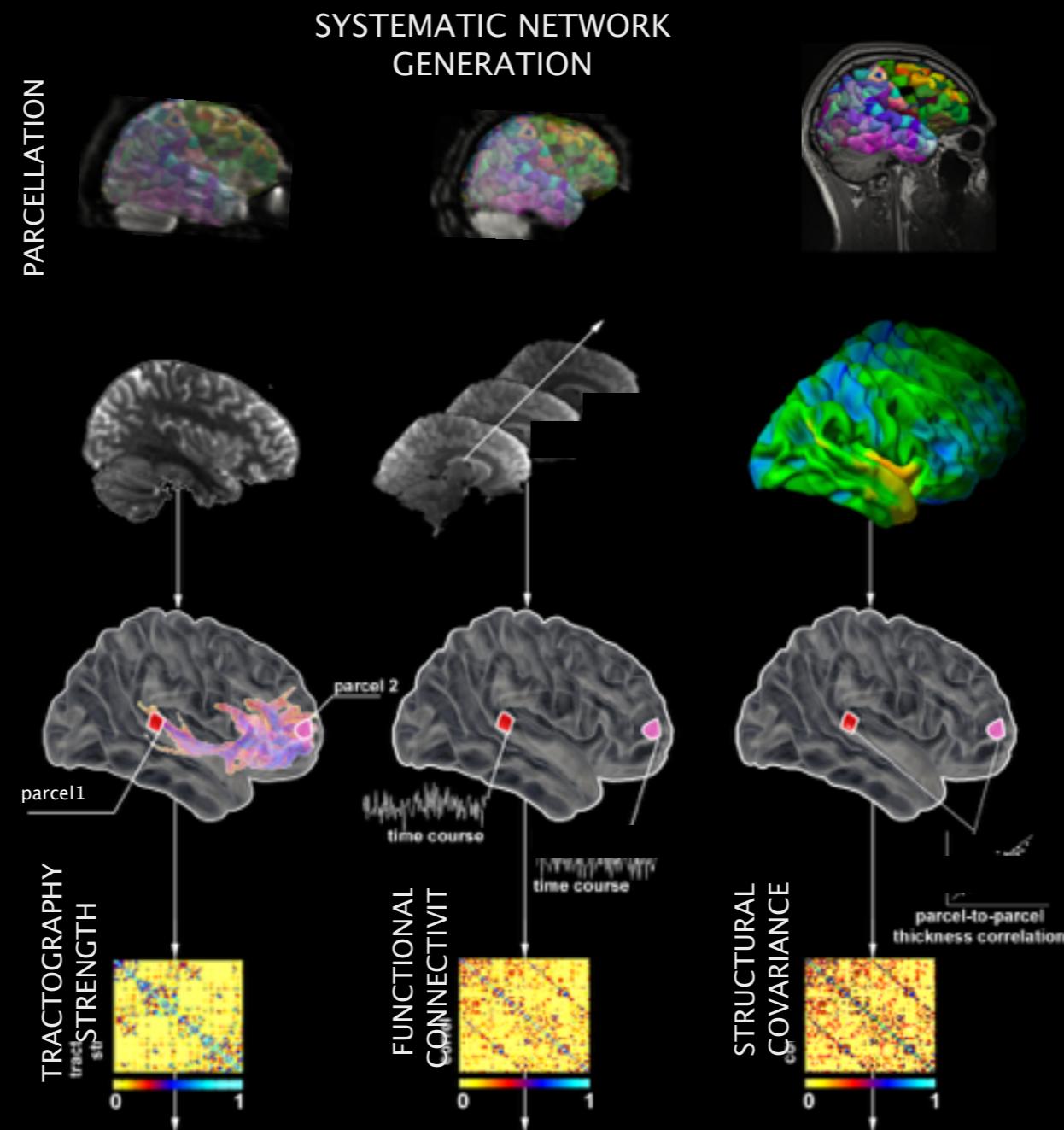


Mori et al. (1999) Ann Neu
Behrens et al. (2007) NIMG

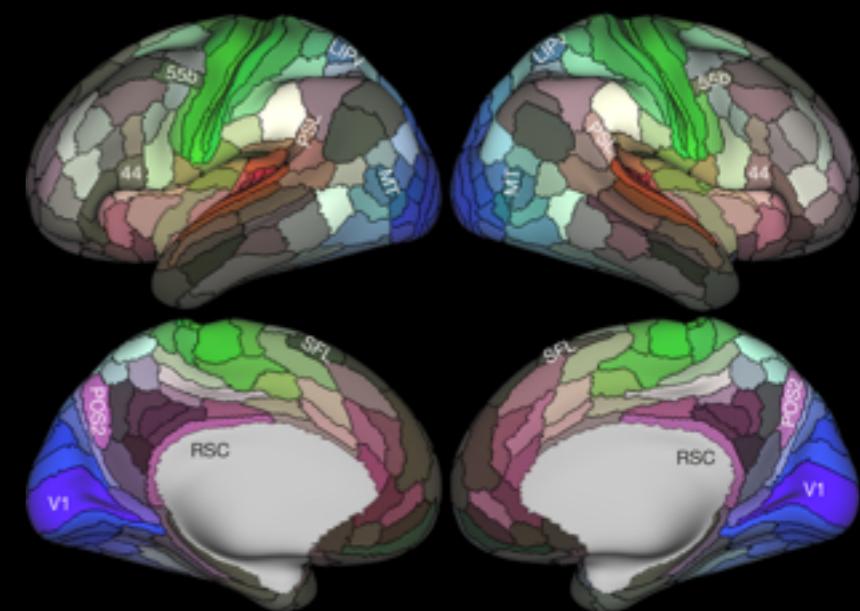
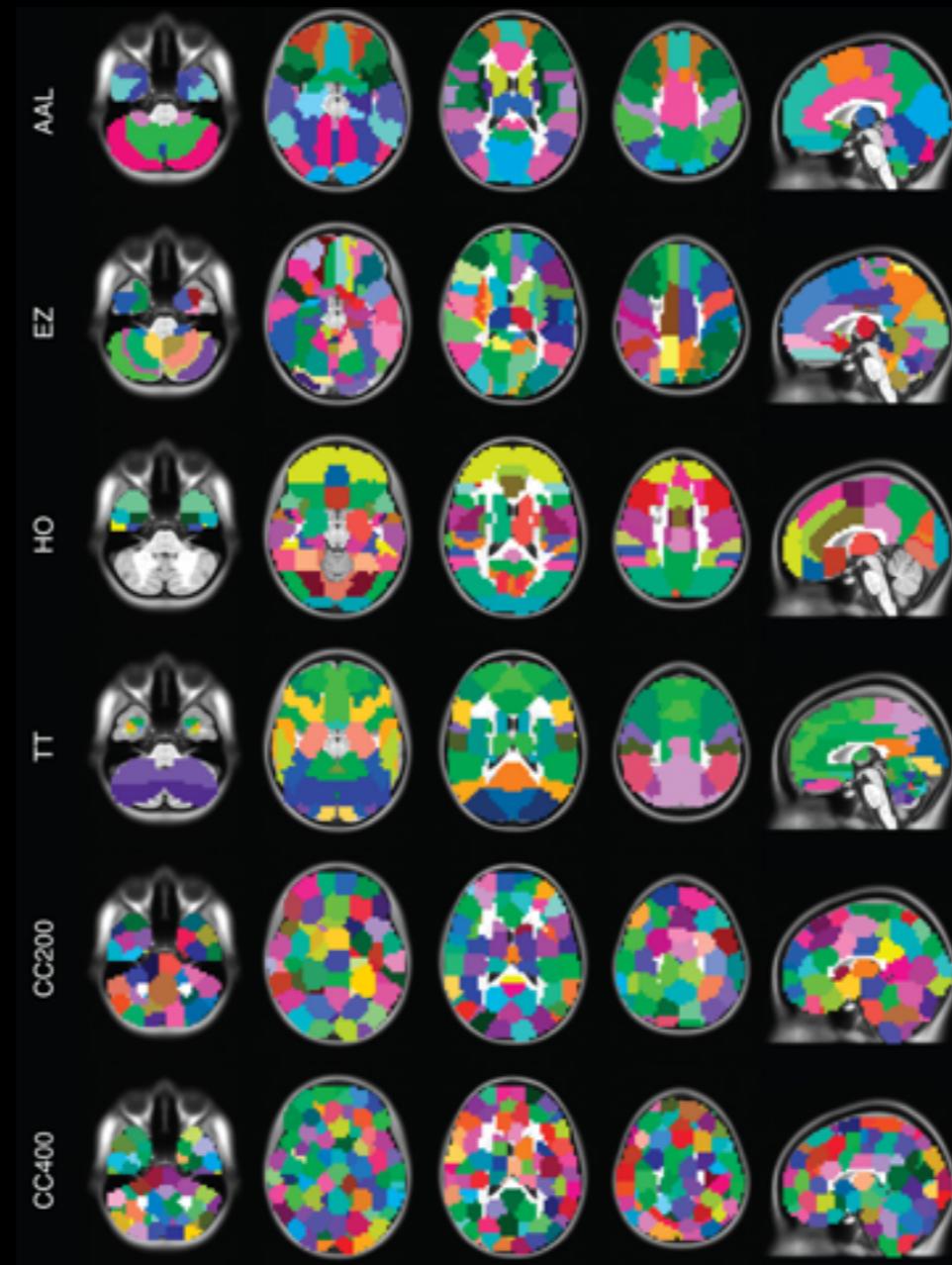
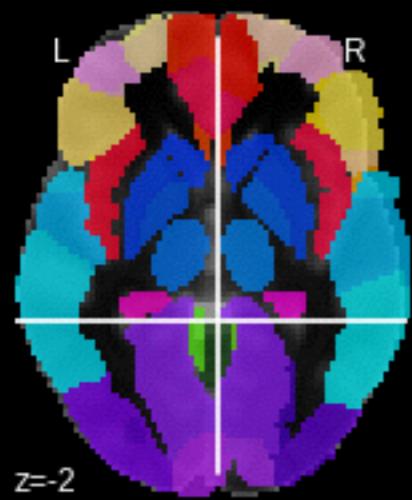
Friston (1994) HBM
Smith (2012) NIMG

Lerch et al. (2006) NIMG
Alexander-Bloch et al. (2013) NRN

CONNECTOME ANALYSIS



DEFINITION OF REGION

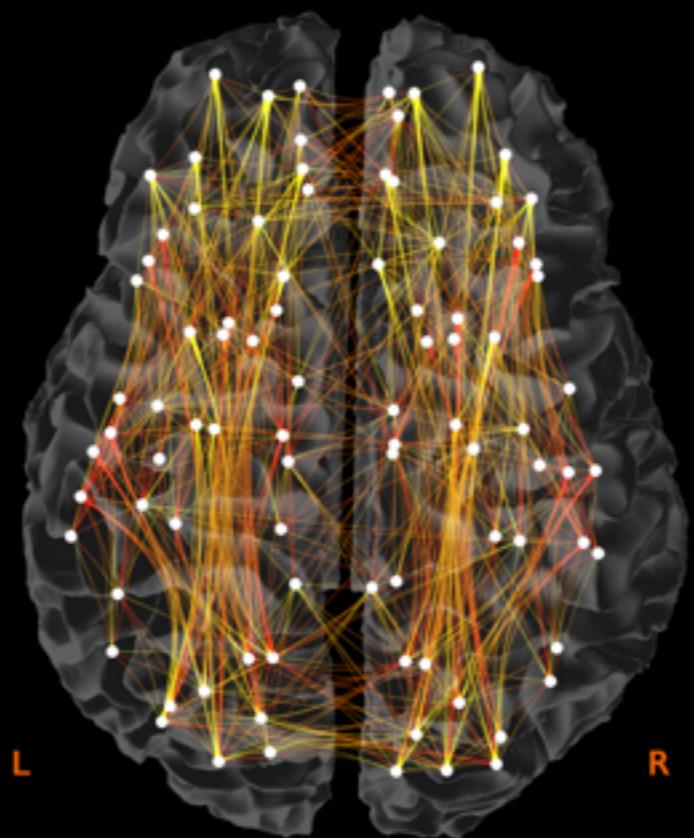


WHAT ASPECTS OF NETWORKS CAN BE MEASURED?

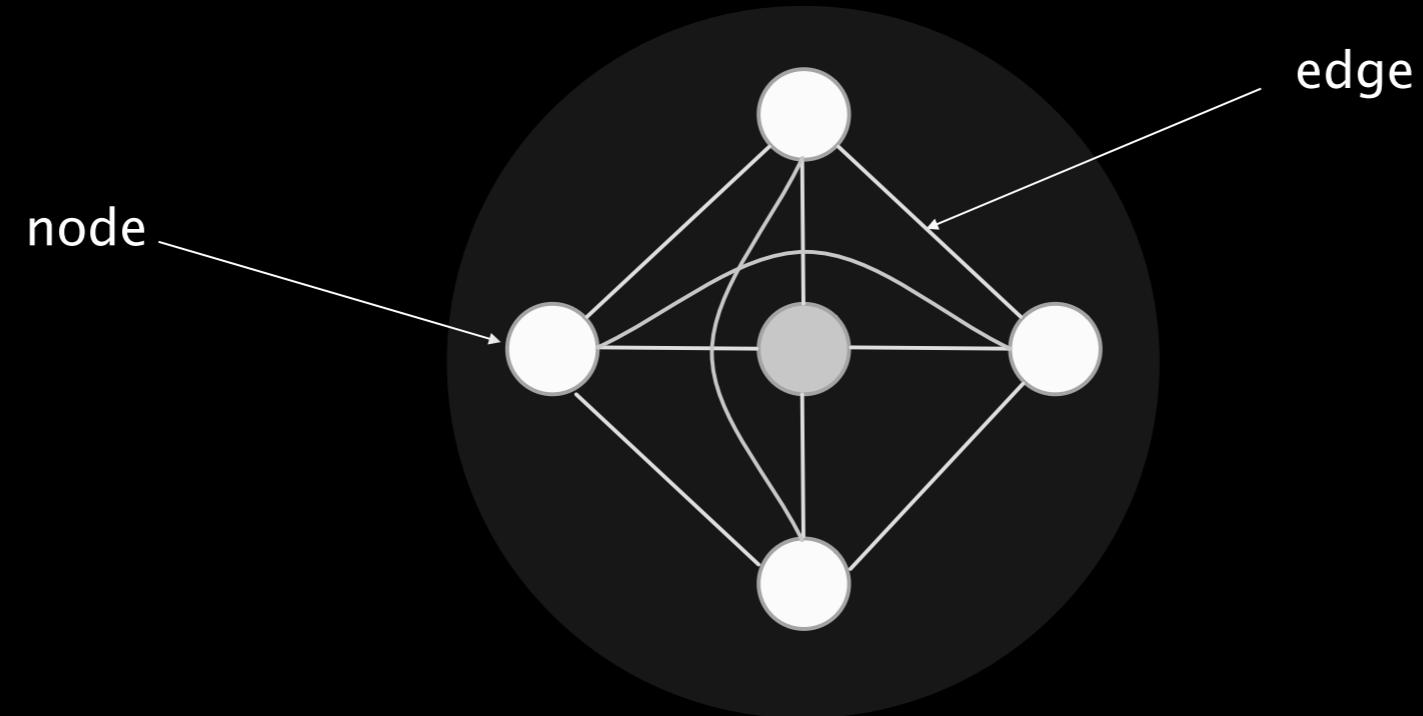
MATRICES AND GRAPHS



CONTROLS

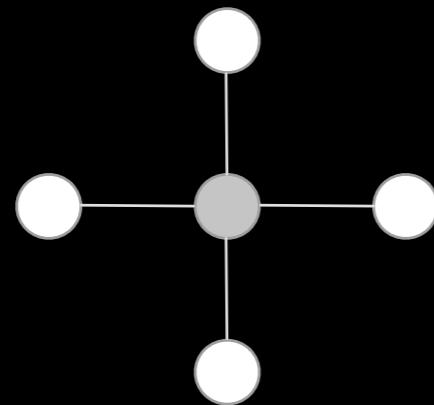


TOPOLOGY



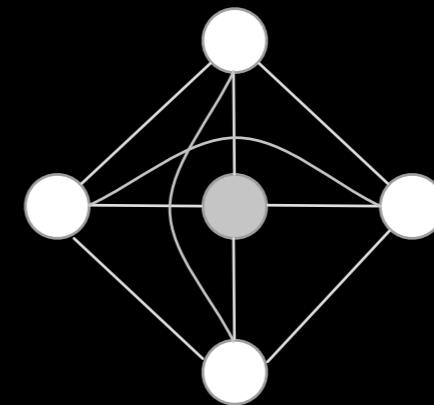
τόπος, *place*, and λόγος, *study*

CLUSTERING COEFFICIENT C / gamma



low C

low local efficiency

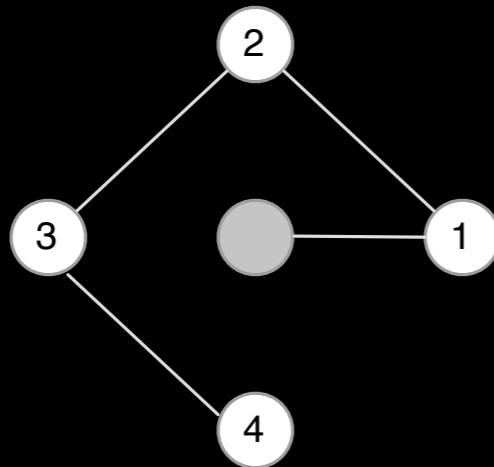


high C

high local efficiency

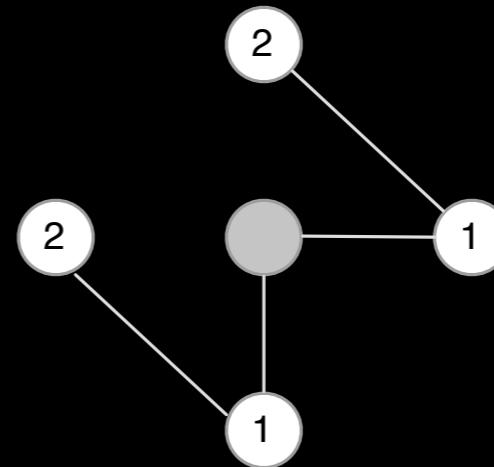
$$c_i = \frac{E_i}{\frac{k_i(k_i - 1)}{2}}.$$

PATH LENGTH P / Lambda



HIGH P

low global efficiency



LOW P

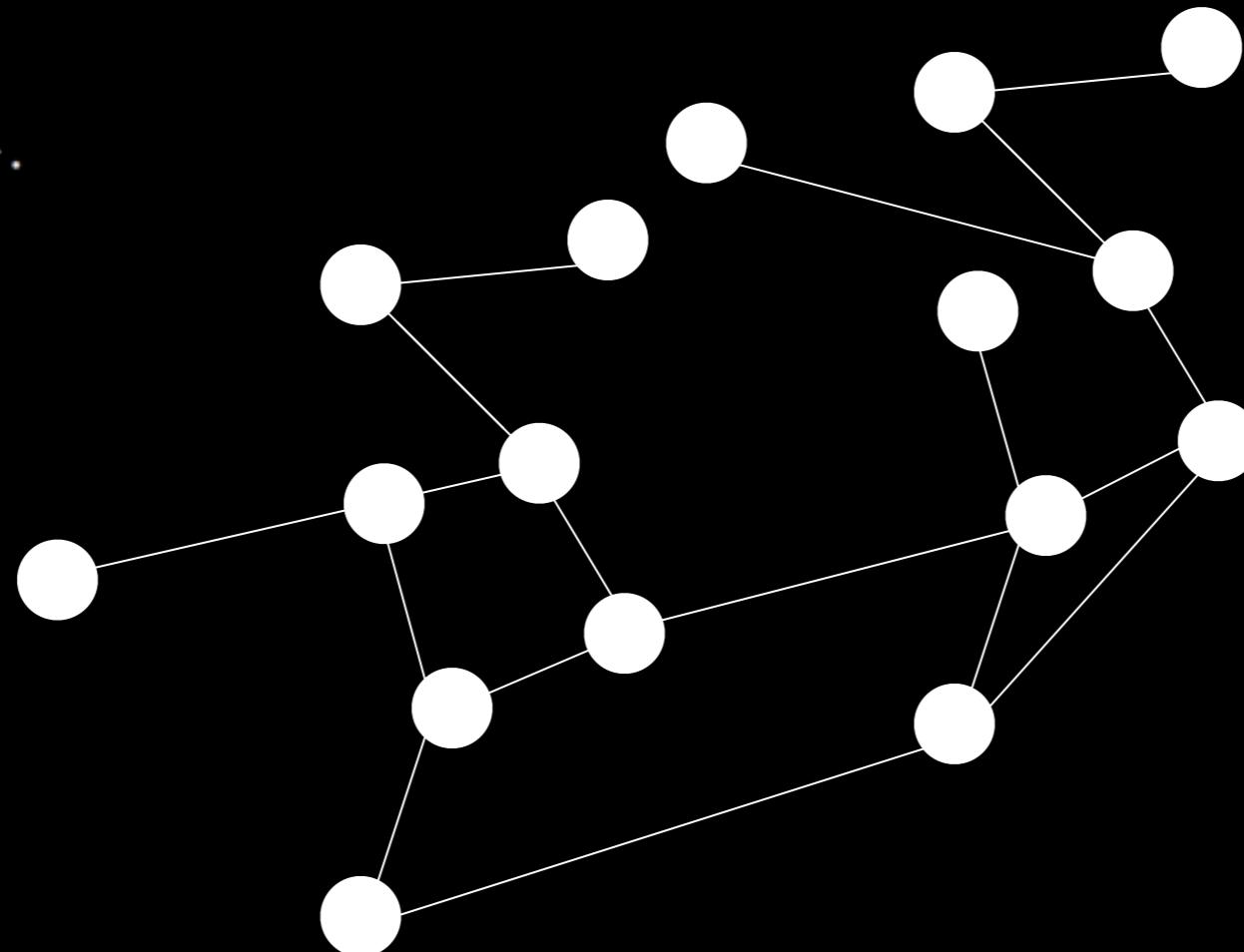
high global efficiency

$$l_i = \frac{1}{n-1} \sum_{i \neq j} \min\{l_{ij}\}.$$

FROM NODES TO NETWORKS

$$l_i = \frac{1}{n-1} \sum_{i \neq j} \min\{l_{ij}\}.$$

$$L = \frac{n}{\sum_{i=1}^n \frac{1}{l_i}}.$$

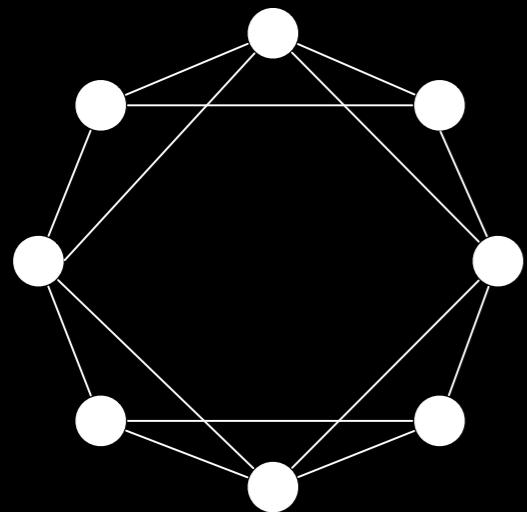


$$c_i = \frac{E_i}{\frac{k_i(k_i-1)}{2}}.$$

$$C = \frac{1}{n} \sum_{i=1}^n c_i.$$

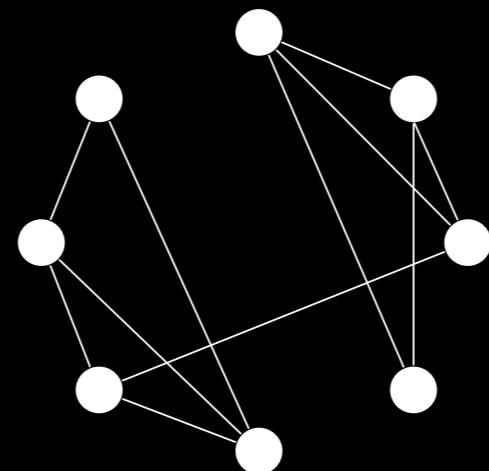
GLOBAL TOPOLOGY

REGULAR



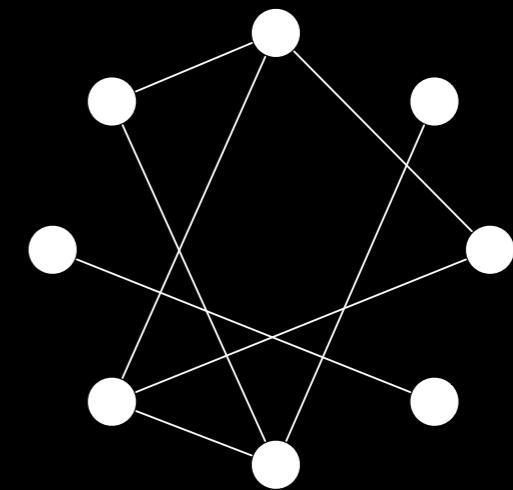
HIGH C
HIGH P

SMALL-WORLD



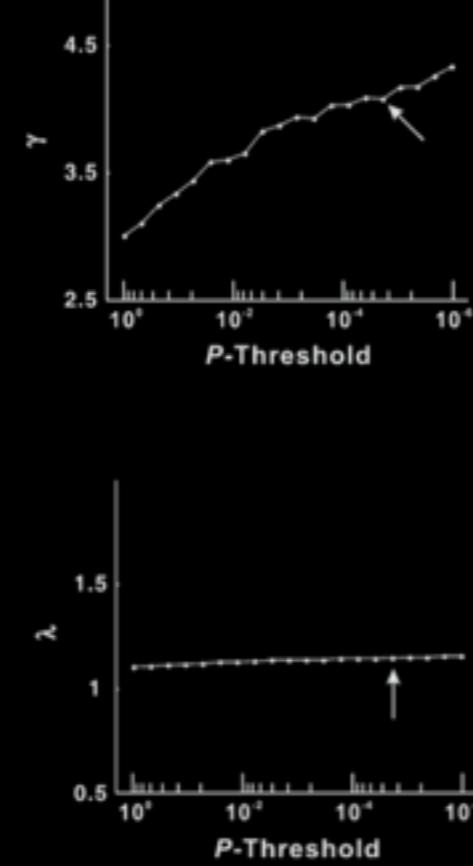
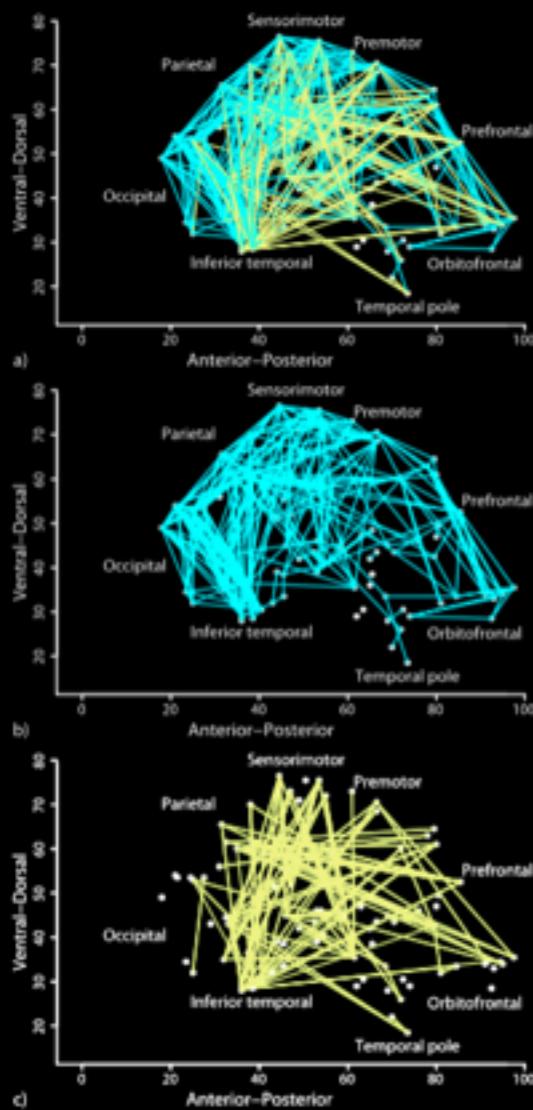
HIGH C
LOW P

RANDOM



LOW C
LOW P

GLOBAL TOPOLOGY



$$\theta = \gamma/\lambda > 1$$

$$\theta = \gamma/\lambda > 1$$

$$\theta = \gamma/\lambda > 1$$

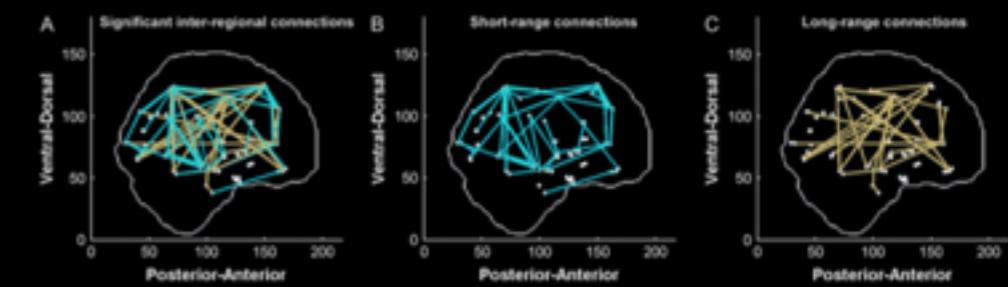
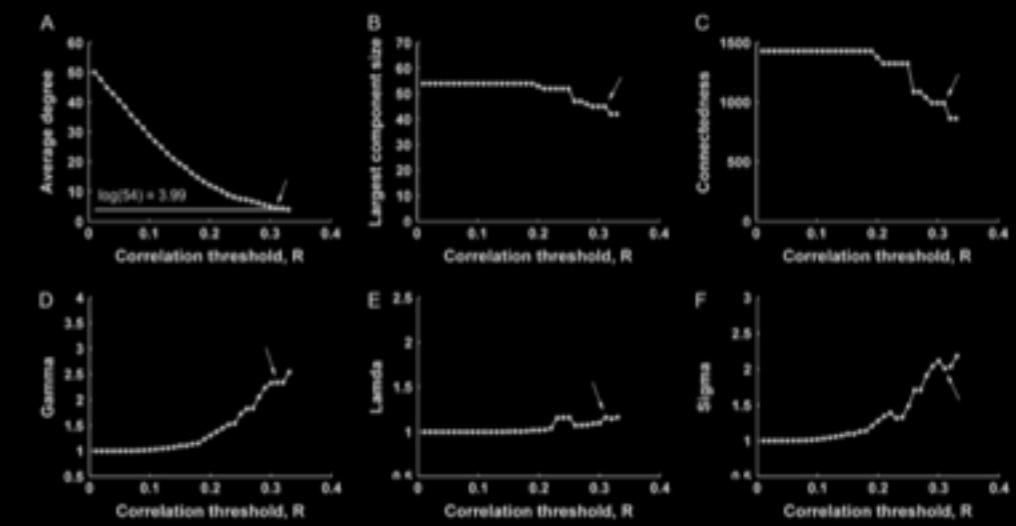


Figure 3. Short- and long-range anatomical connections in the anatomical space. (A) One hundred and four undirected edges ($\sim 7.2\%$ of the 1401 possible connections among regions) representing the significant connections were shown in a sagittal view of the brain. Edges were classified into (B) short-range connections ($D < 75$ mm, red) and (C) long-range connections ($D > 75$ mm, blue). The locations of the nodes indicated the y and z coordinates of the regional centroids in Talairach space.



INTERMEDIATE TOPOLOGY: MODULARITY

Modularity and community structure in networks

M. E. J. Newman*

Department of Physics and Center for the Study of Complex Systems, University of Michigan, Ann Arbor, MI 48109

Edited by Brian Skyrms, University of California, Irvine, CA, and approved April 19, 2006 (received for review February 26, 2006)

Many networks of interest in the sciences, including social networks, computer networks, and metabolic and regulatory networks, are found to divide naturally into communities or modules. The problem of detecting and characterizing this community structure is one of the outstanding issues in the study of networked systems. One highly effective approach is the optimization of the quality function known as “modularity” over the possible divisions of a network. Here I show that the modularity can be expressed in terms of the eigenvectors of a characteristic matrix for the network, which I call the modularity matrix, and that this expression leads to a spectral algorithm for community detection that returns results of demonstrably higher quality than competing methods in shorter running times. I illustrate the method with applications to several published network data sets.

clustering | partitioning | modules | metabolic network | social network

Many systems of scientific interest can be represented as networks, sets of nodes or vertices joined in pairs by lines or edges. Examples include the internet and the worldwide web, metabolic networks, food webs, neural networks, communication and distribution networks, and social networks. The study of

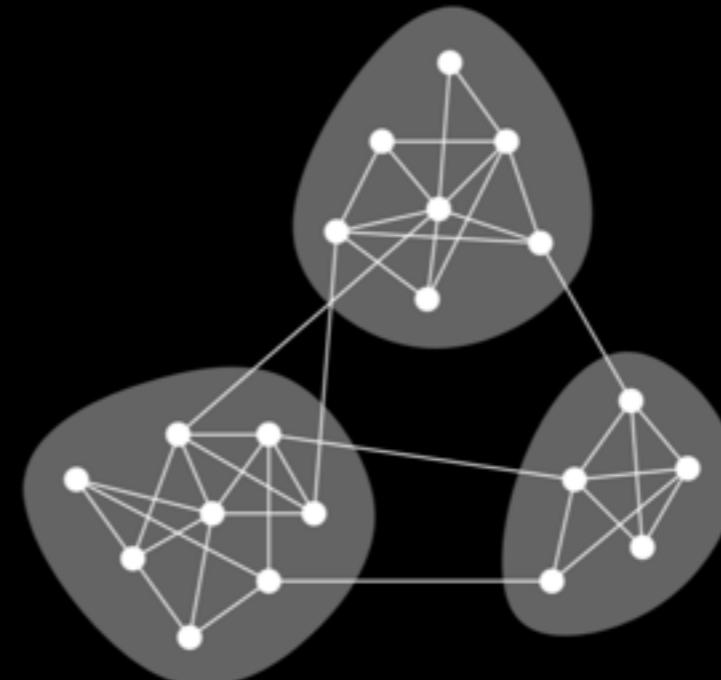
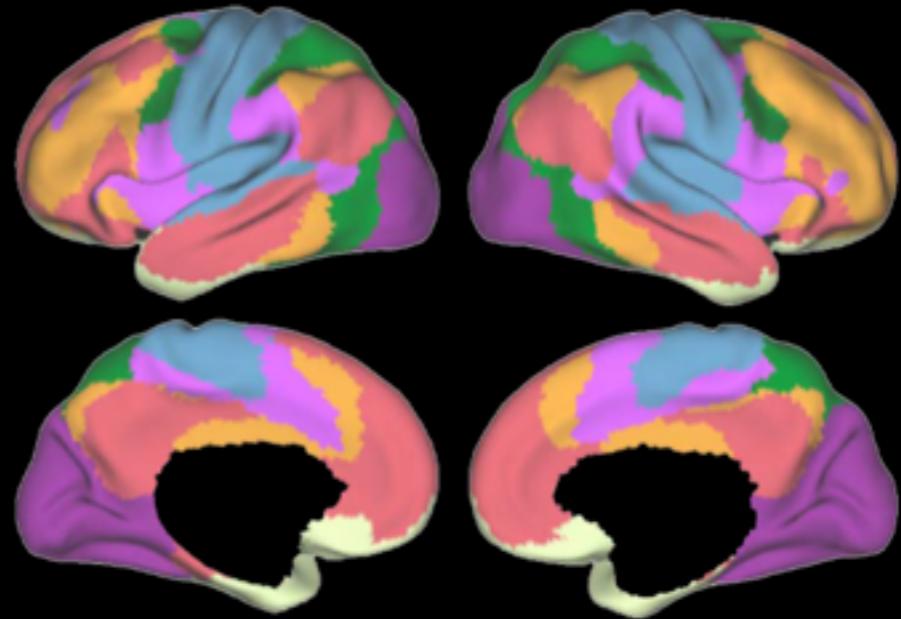
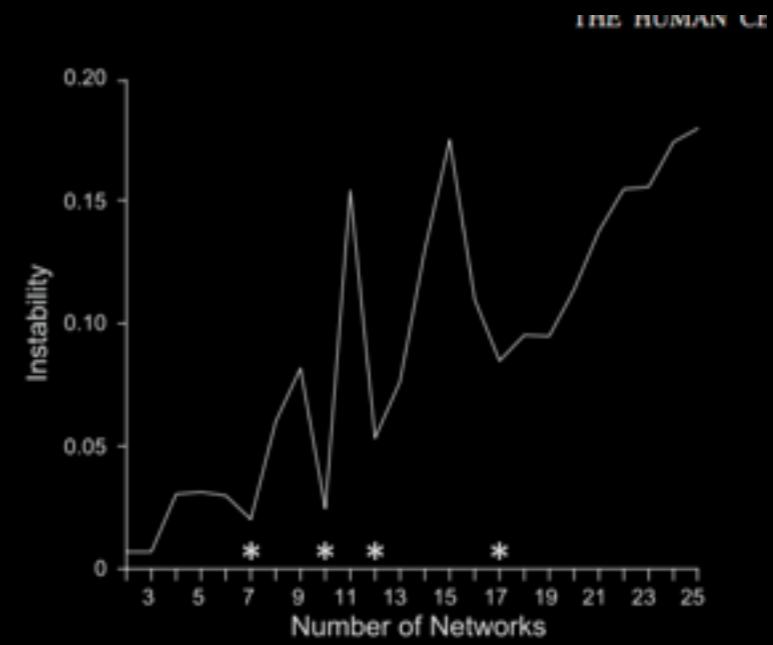
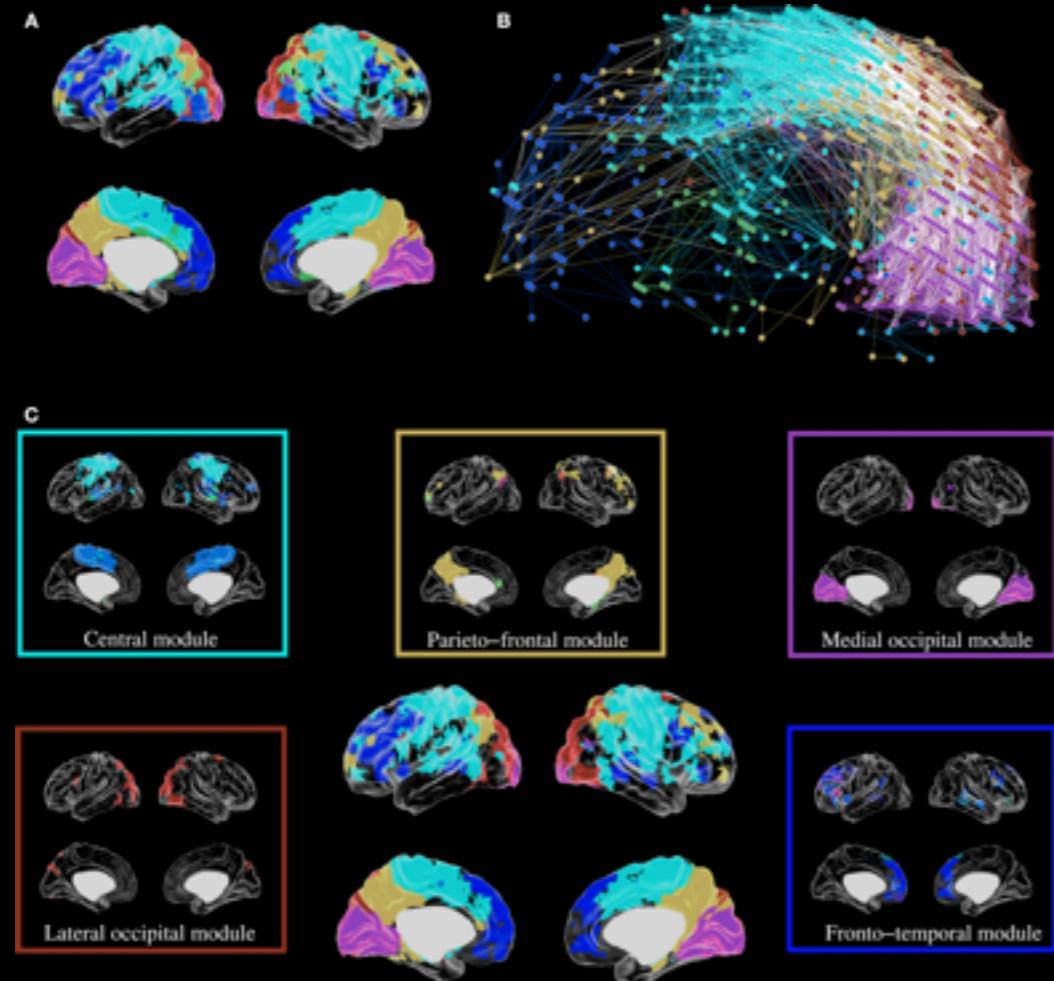


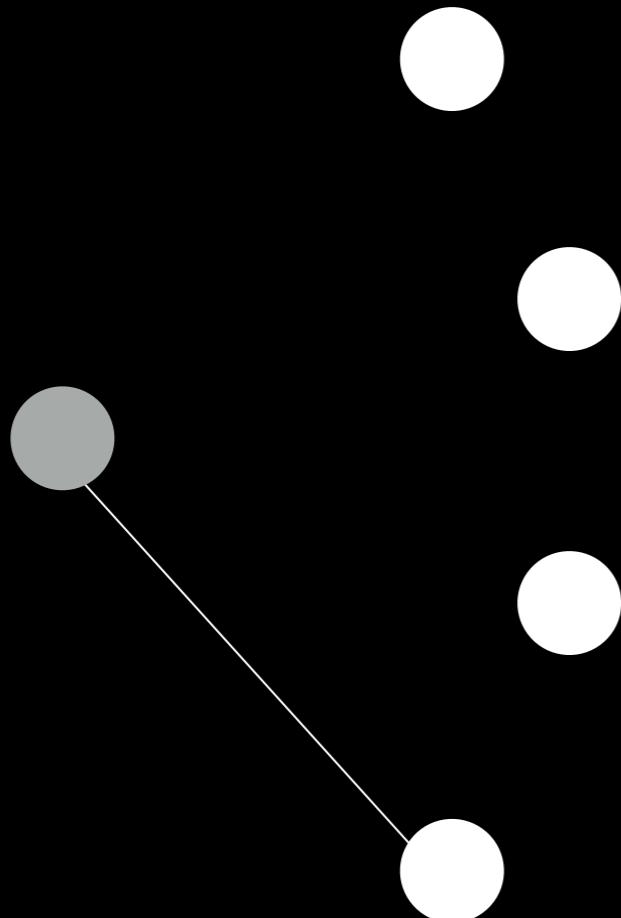
Fig. 1. The vertices in many networks fall naturally into groups or communities, sets of vertices (shaded) within which there are many edges, with only a smaller number of edges between vertices of different groups.

INTERMEDIATE TOPOLOGY: MODULARITY

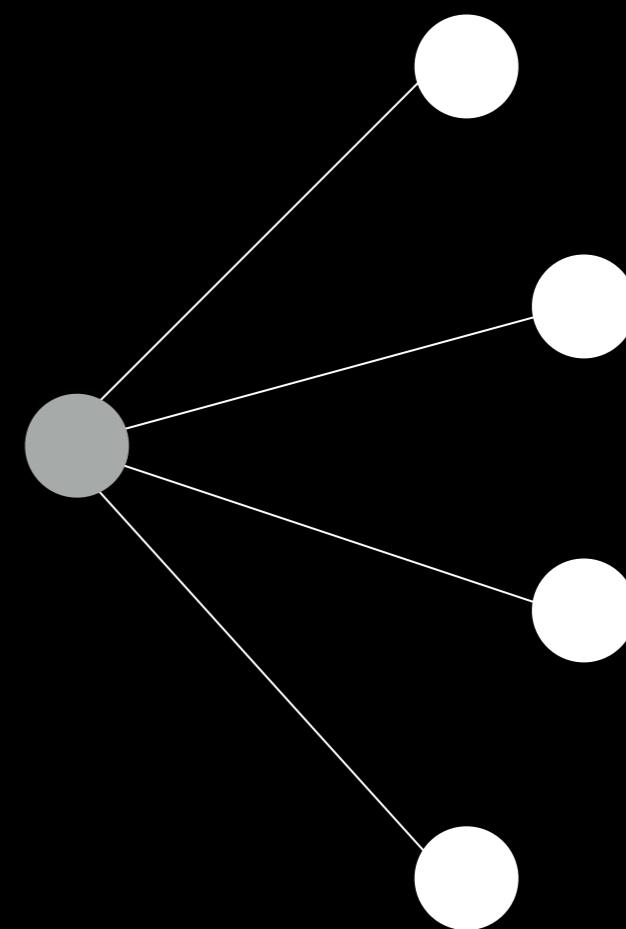


NODAL TOPOLOGY: CENTRALITY

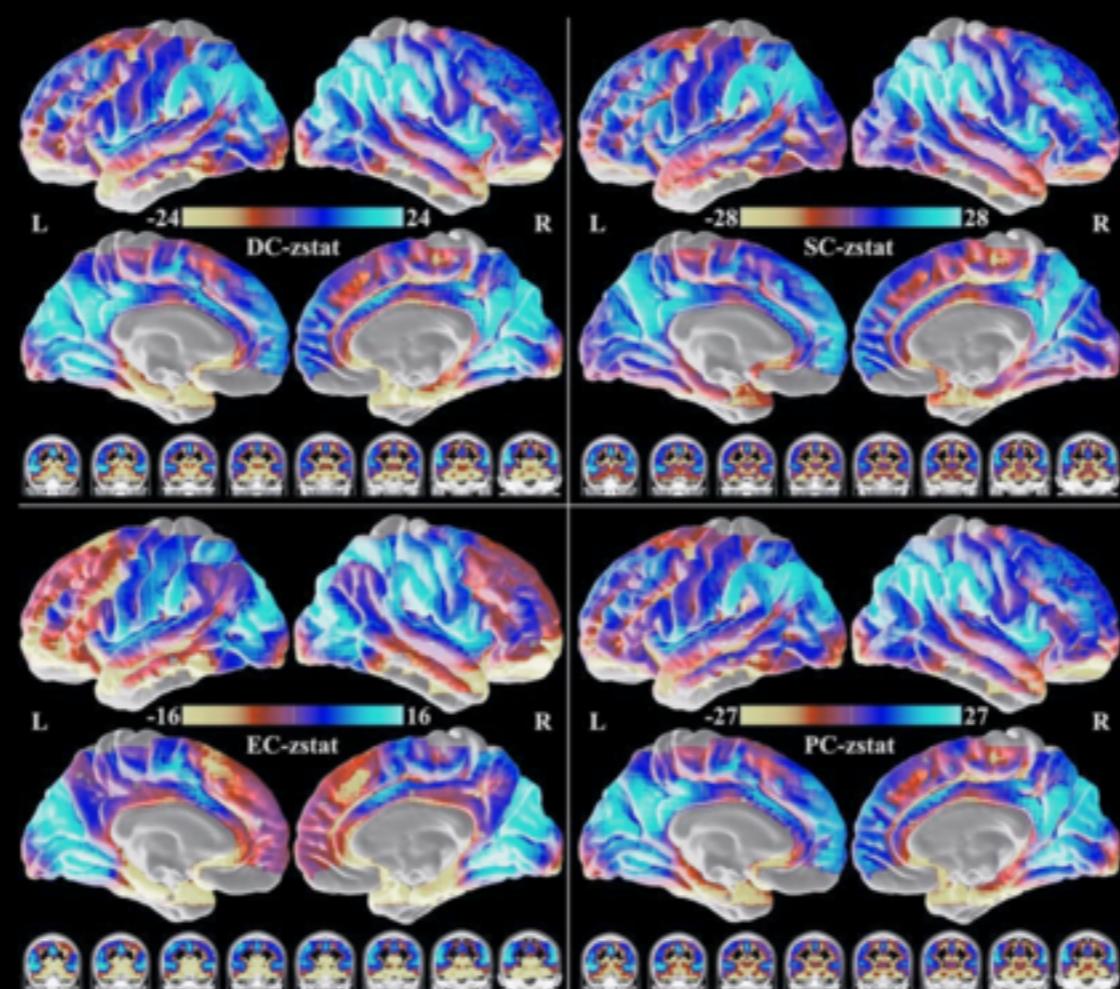
LOW DEGREE



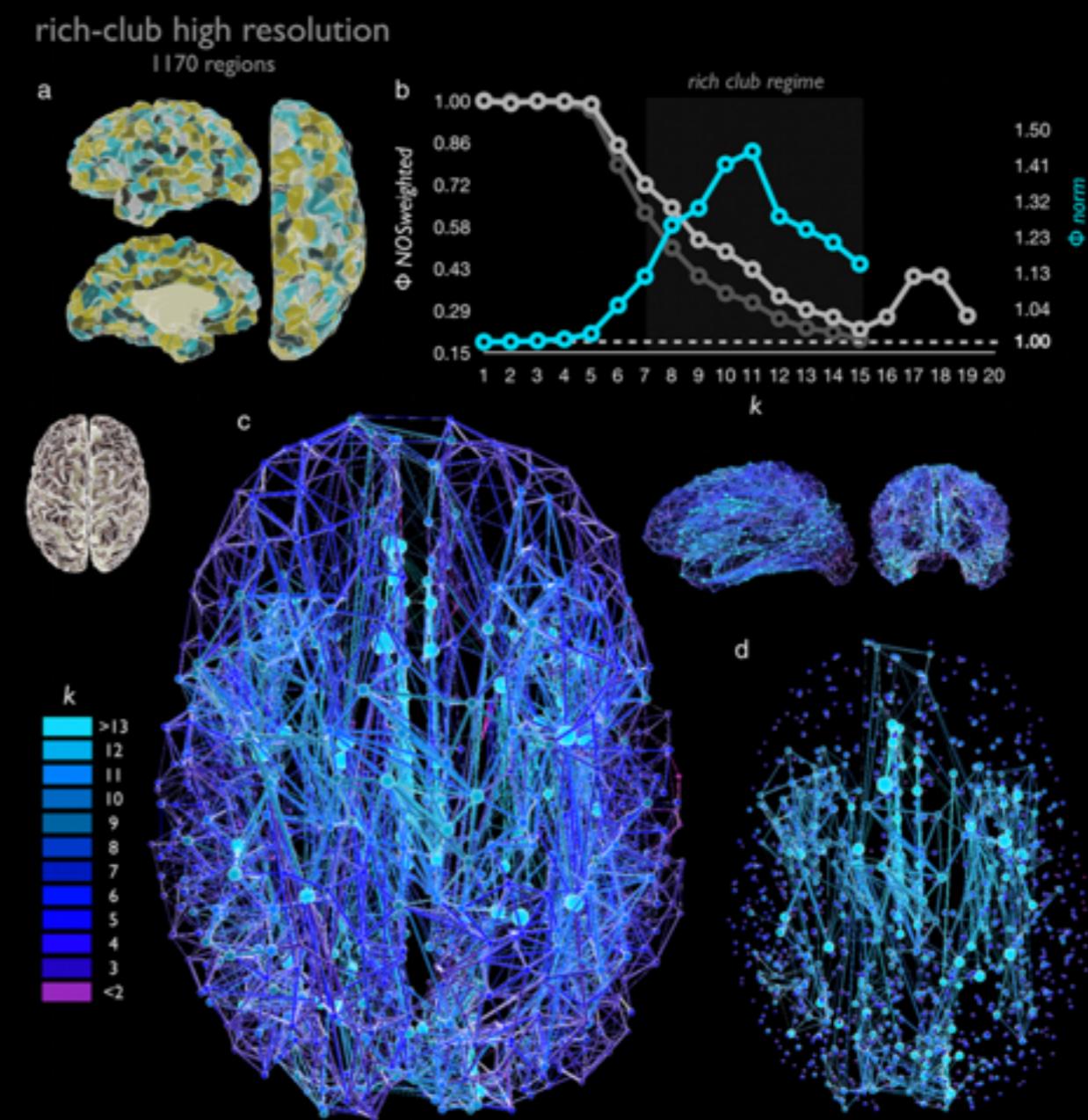
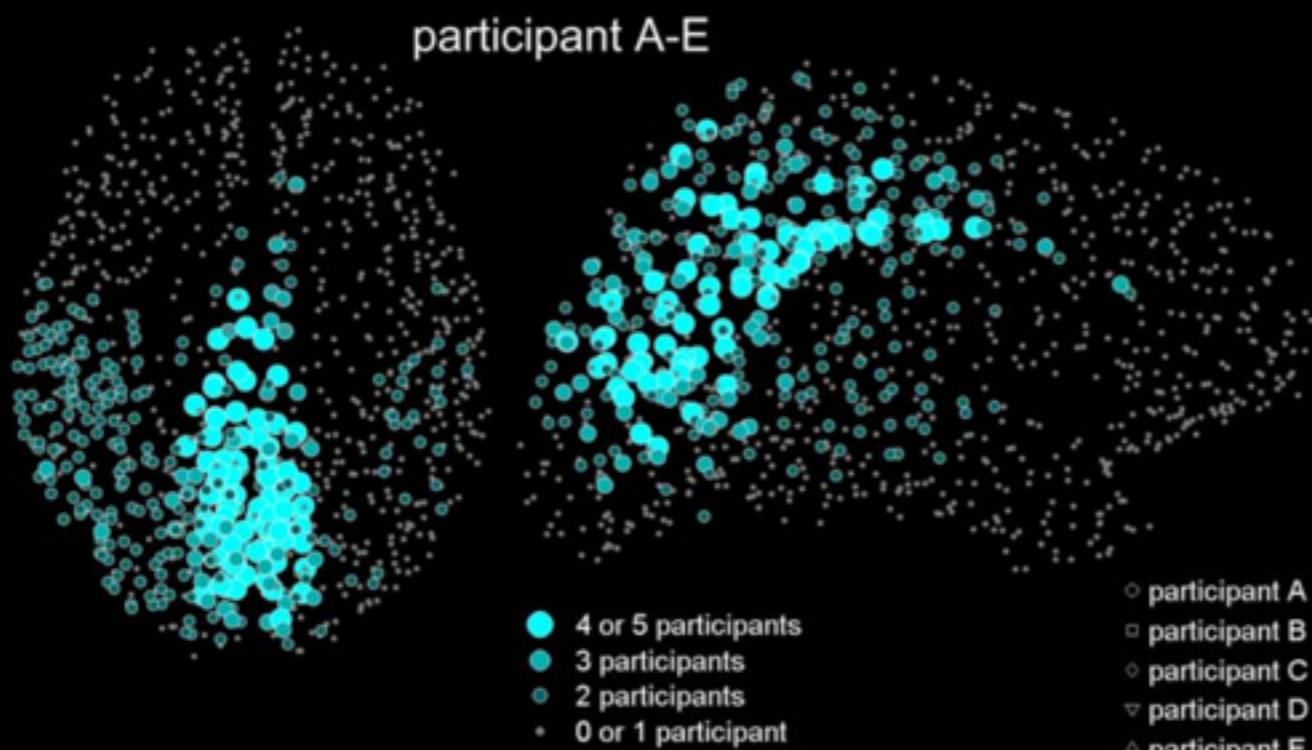
HIGH DEGREE



NODAL TOPOLOGY: CENTRALITY



NODAL TOPOLOGY: RICH-CLUB AND CORES



INTERIM SUMMARY

HEALTHY BRAIN CONNECTOME IS FOUND TO BE
CHARACTERIZED BY SMALL-WORLD TOPOLOGY

HIGH LOCAL AND GLOBAL EFFICIENCY

HIGHLY REPLICABLE FUNCTIONAL COMMUNITIES:
DMN,TPN,SN,VN,...

BACKBONE/CORE/RICH-CLUB STRUCTURE
PROVIDES STABILITY OF NETWORK AND MEDIATES
CROSS-MODULE COMMUNICATION

STRUCTURAL SCAFFOLD OF THE NETWORK
CAN BE USED TO SIMULATE FUNCTIONAL DYNAMICS
WITH REASONABLE GOF