Network Science seminar 2018

Masanori Shimono
Faculty of Medicine, Kyoto University
Hakubi/LEADER researcher

[An introductory talk]
From Neuroscience to Network Science

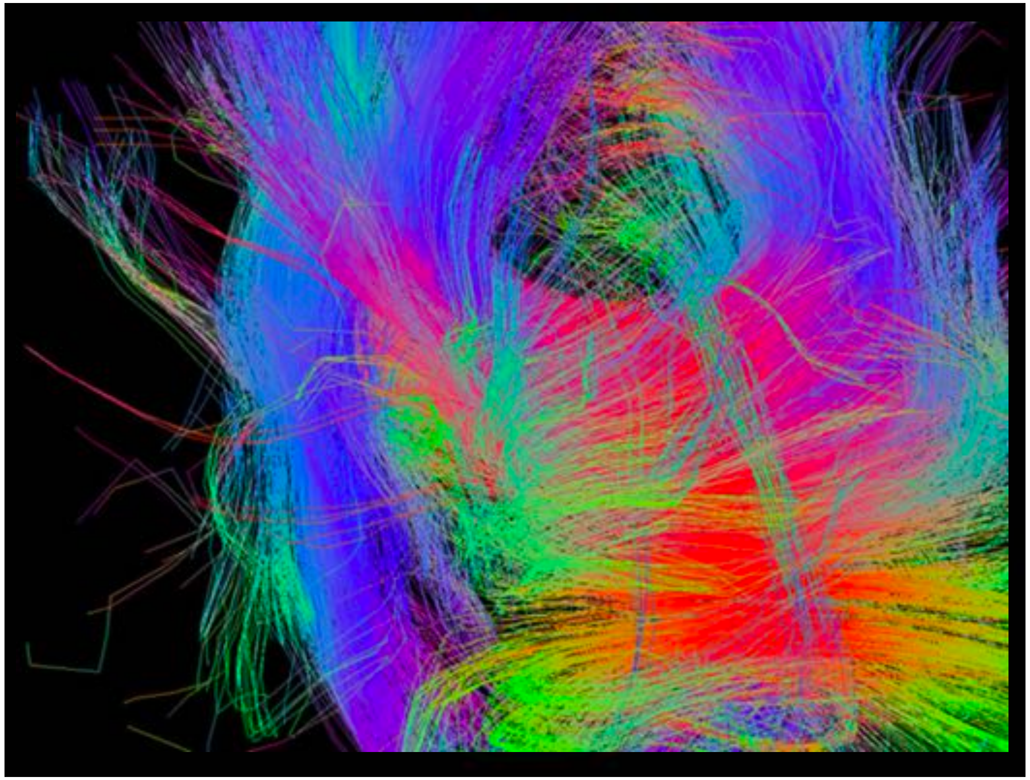
Masanori Shimono
Faculty of Medicine, Kyoto University
Hakubi/LEADER researcher

[Historical bases]

Is brain a network system?

Is brain a network system?

	Macro	Micro
Structure		
Activity		



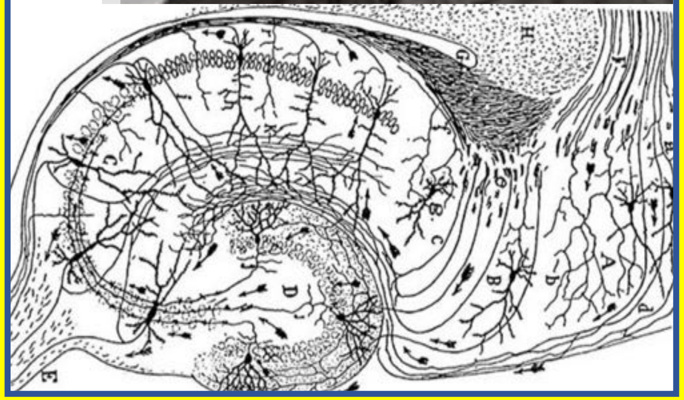
Is brain a network system?

	Macro	Micro
Structure		
Activity		

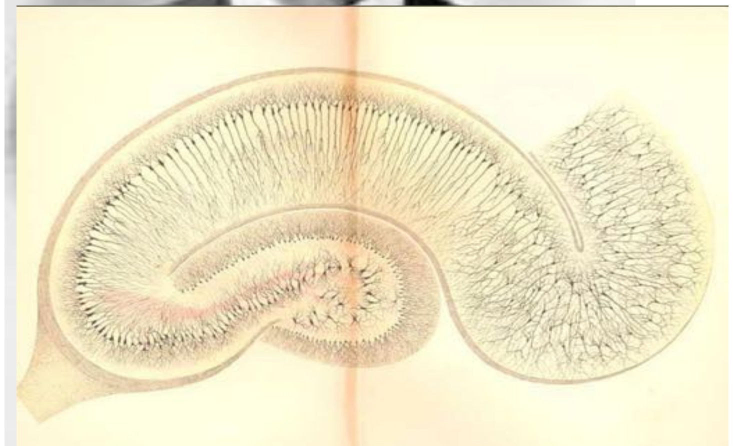
- **Two coins by/for Cajal and Golgi**

Santiago Ramón y Cajal（1852-1934）

Camillo Golgi（1843 – 1926）



Nobel prize
in physiology or medicine
1906

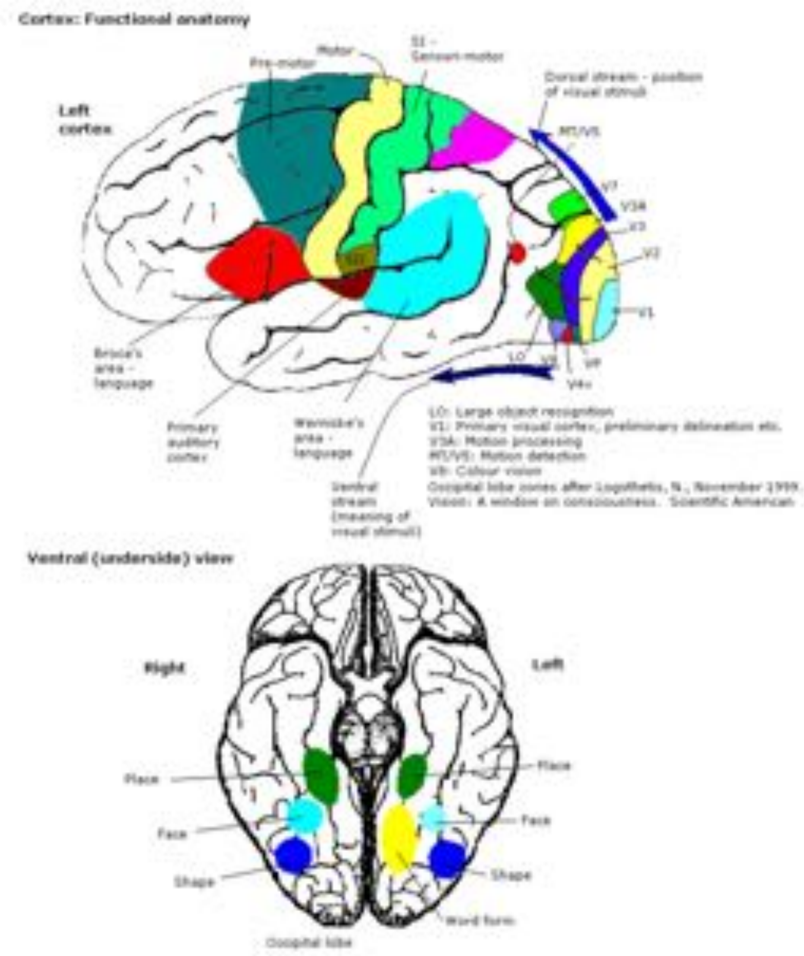


ニューロン説　Segmentation　vs.　Integration　網状説

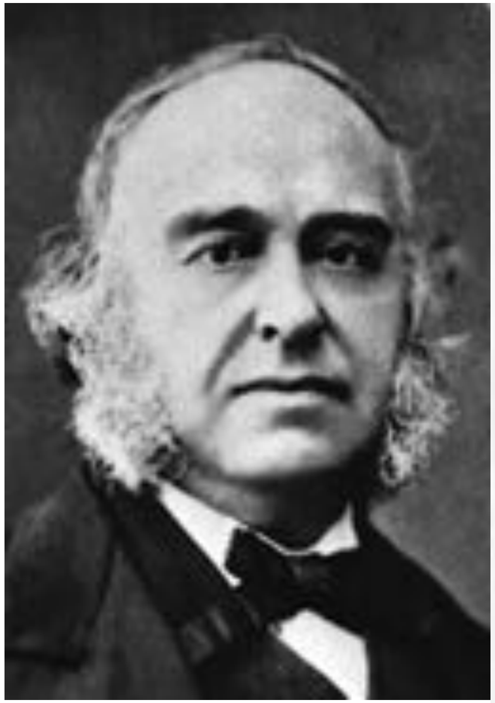
Is brain a network system?

	Macro	Micro
Structure		
Activity	Segmentation	

- **機能局在論**



Paul Broca
(1824–1880)



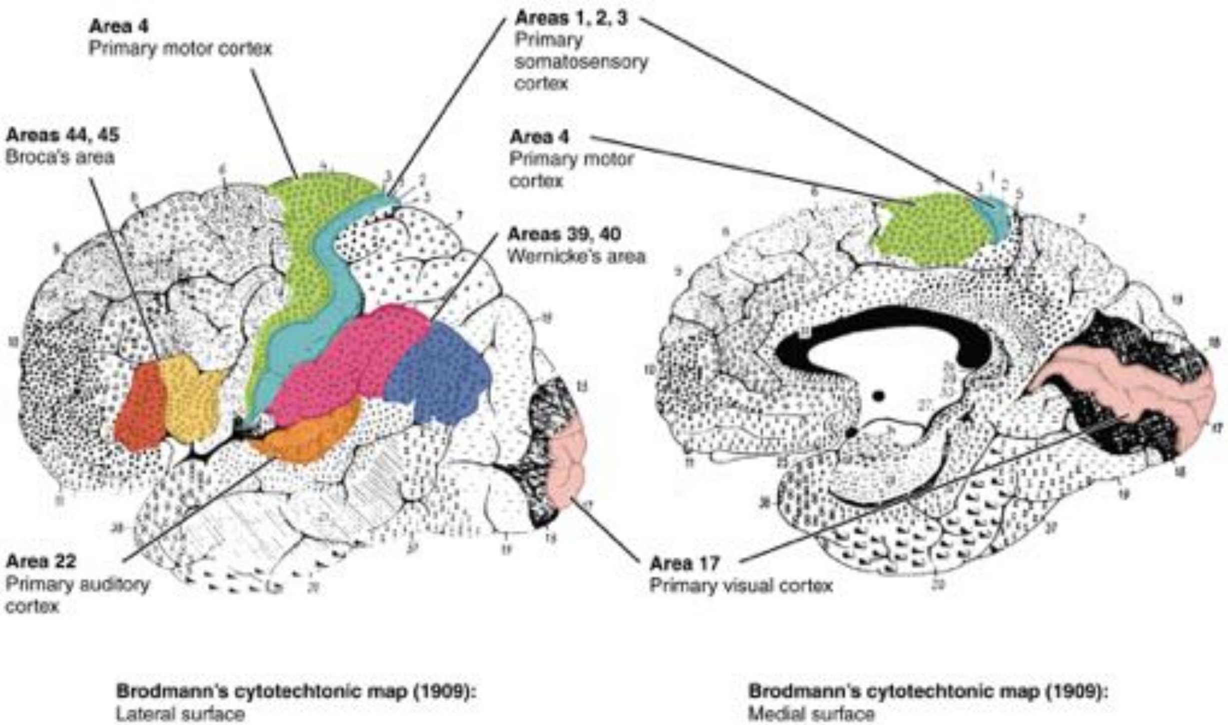
Carl Wernicke
(1848–1905)

Is brain a network system?

	Macro	Micro
Structure	Segmentation	
Activity		

- **ブロードマン地図 (組織構築論学的区分)**

Korbinian Brodmann　(1868-1918)



Is brain a network system?

	Macro	Micro
Structure		
Activity		Segmentation

- おばあちゃん細胞仮説

Jerzy Konorski
(1903-1973)

Gnostic neuron (認識細胞) 1967

Jerome Ysrael Lettvin
(1920- 2011)

Granma. neuron ~ 1969

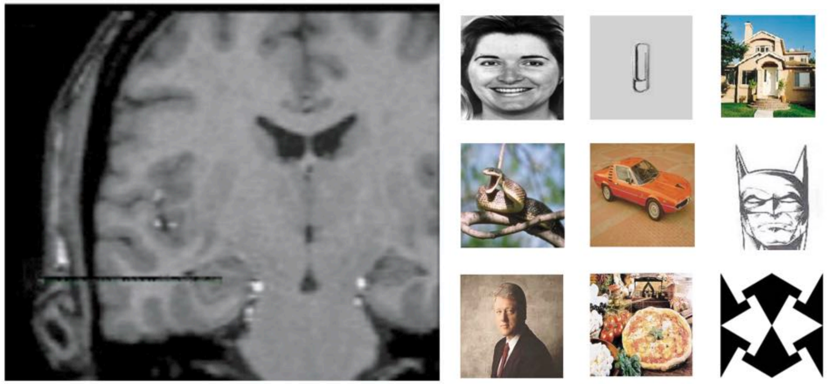
Segmentation once governed everything!

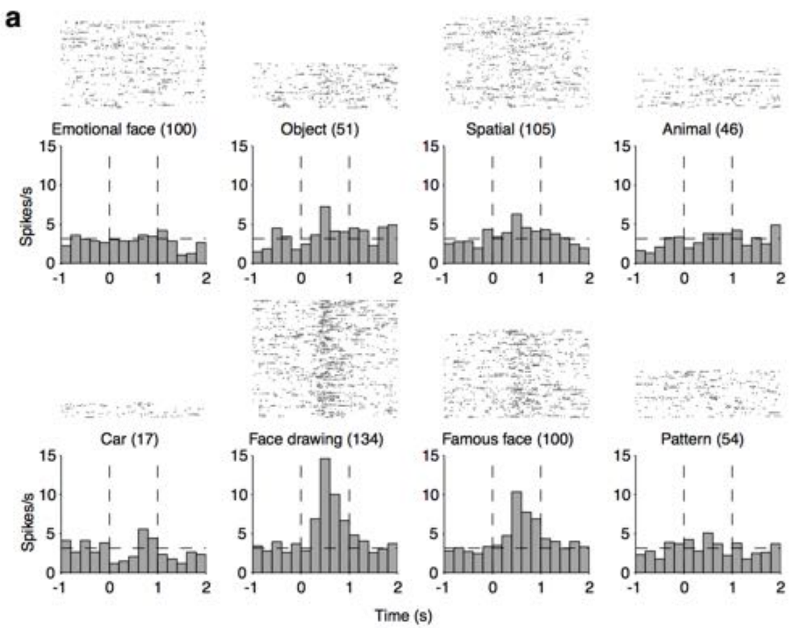
BUT

Is brain a network system?

	Macro	Micro
Structure		
Activity		Segmentation

- Sparse rather than single





Published online 22 June 2005 | Nature | doi:10.1038/news050620-7

News

Jennifer Aniston strikes a nerve

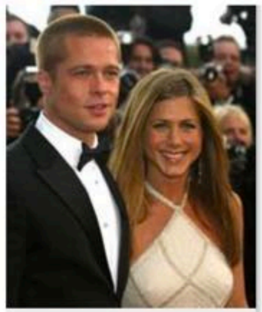
Single brain cells show selective response to specific celebrity photos.

Roxanne Khamsi

Is a single cell in your brain devoted to Jennifer Aniston or Bill Clinton? Maybe so, according to new research.

A recent experiment showed that single neurons in people's brains react to the faces of specific people. Researchers see the findings as evidence that our brains use fewer cells to decode a given image than previously thought.

The subject of visual processing has sparked much scientific speculation in the past. Exactly how our brains extract meaning from an image remains unclear. At one end of the spectrum of possibilities, a network of cells would process various bits of information in a scene and piece it all together to form an understandable picture.



Snaps of Aniston made a single neuron in one subject's brain light up

© Photo/Lionel Cironneau

Opinion

Cell PRESS

Sparse but not 'Grandmother-cell' coding in the medial temporal lobe

R. Quian Quiroga[1,2,3], G. Kreiman[4,5], C. Koch[2] and I. Fried[3,6]

[1] Department of Engineering, University of Leicester, LE1 7RH, Leicester, UK
[2] Computation and Neural Systems, California Institute of Technology, 91125 Pasadena, CA, USA
[3] Division of Neurosurgery, David Geffen School of Medicine and Semel Institute for Neuroscience and Human Behavior, University of California Los Angeles, 90095 Los Angeles, CA, USA
[4] Division of Neuroscience and Ophthalmology, Children's Hospital Boston, Harvard Medical School, 02115 Boston, MA, USA
[5] Center for Brain Science, Harvard University, 02138 Cambridge, MA, USA
[6] Functional Neurosurgery Unit, Tel-Aviv Medical Center and Sackler Faculty of Medicine, Tel-Aviv University, 69978 Tel-Aviv, Israel

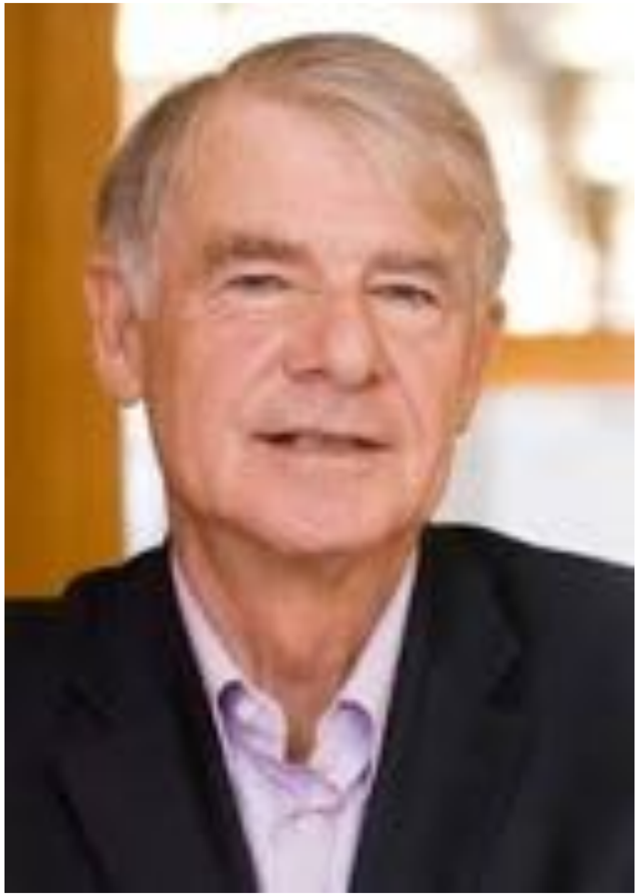
Kreiman, et al. (2000) Nat. Neurosci. Quiroga et al. (2007) Nat. Neurosci.

Is brain a network system?

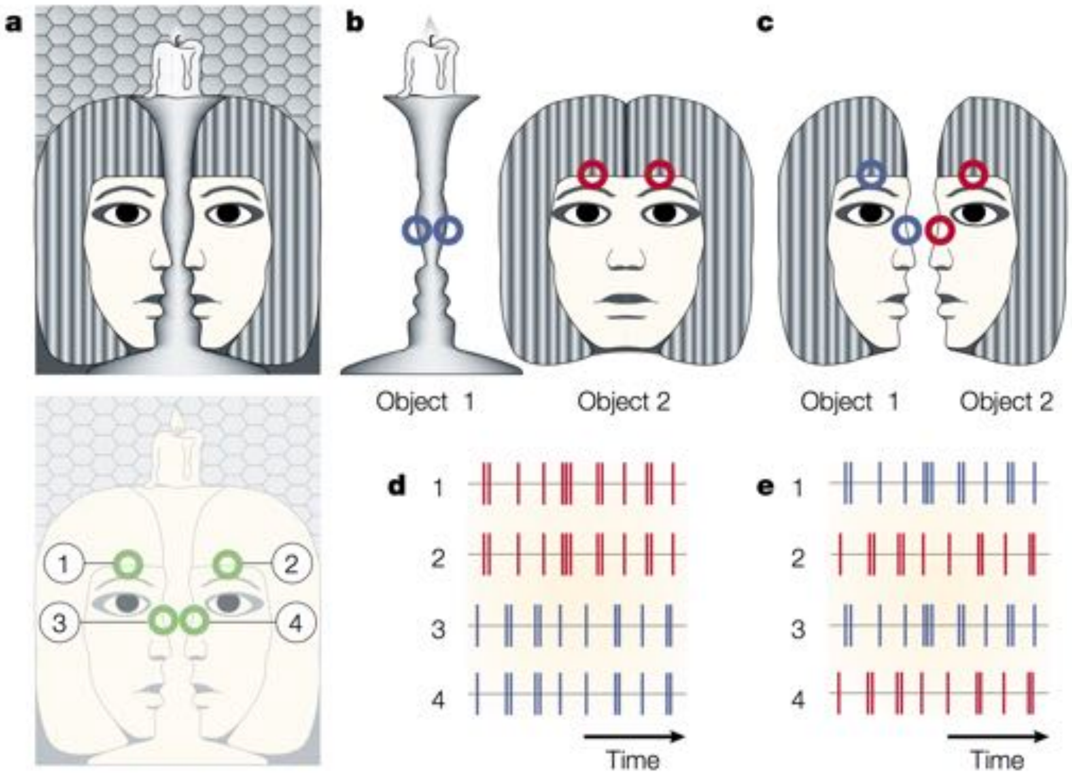
	Macro	Micro
Structure		
Activity	Integration	

- Binding problem

Wolf Singer



Unsolved question !!



Engel et al. (2000) Nat. Rev.

Integration with networks has been realized as an important issue before 2000.

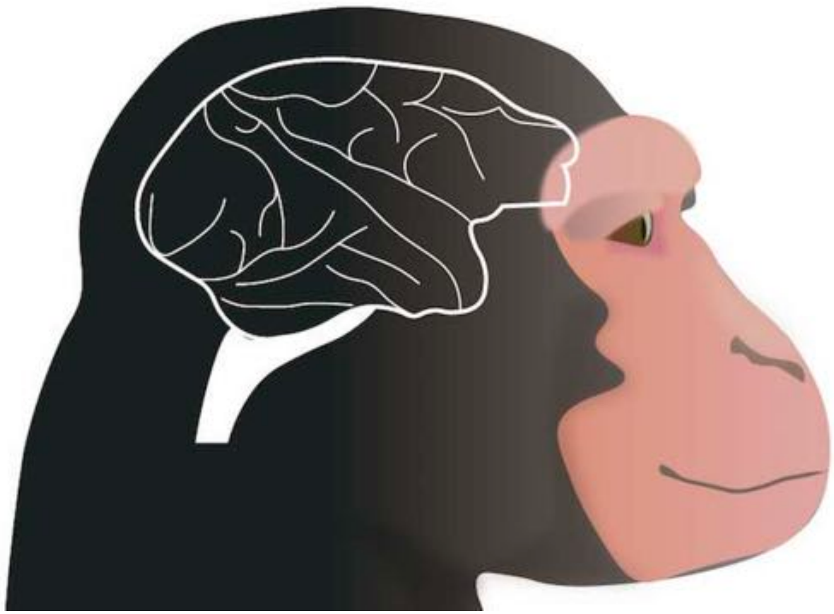
Data acquisition bases
for
Network approach

Direct origins of network neuroscience

Network data acquisition

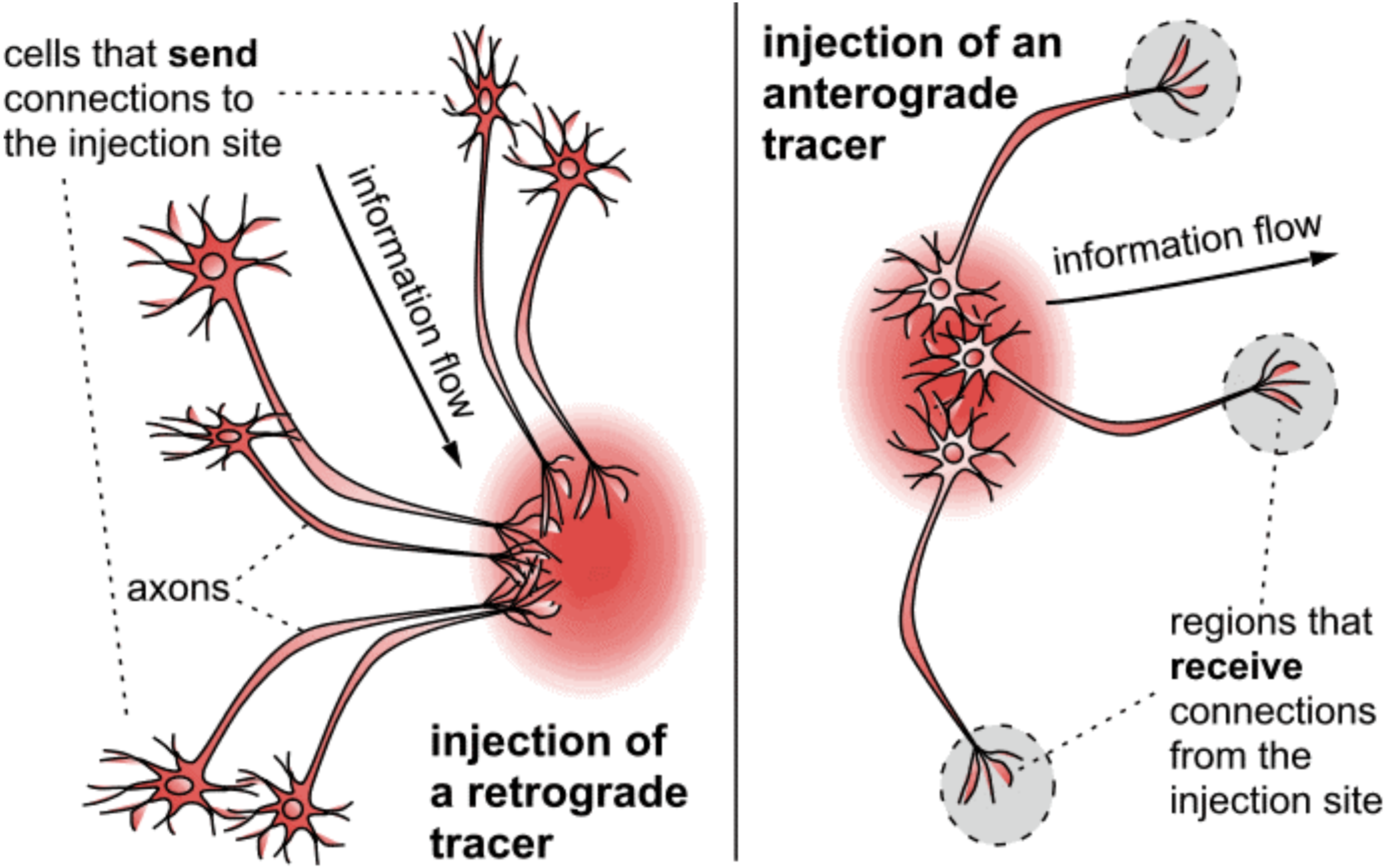
	Macro	Micro
Structure	Integration	
Activity		

In the case of monkey



Tracer Injection

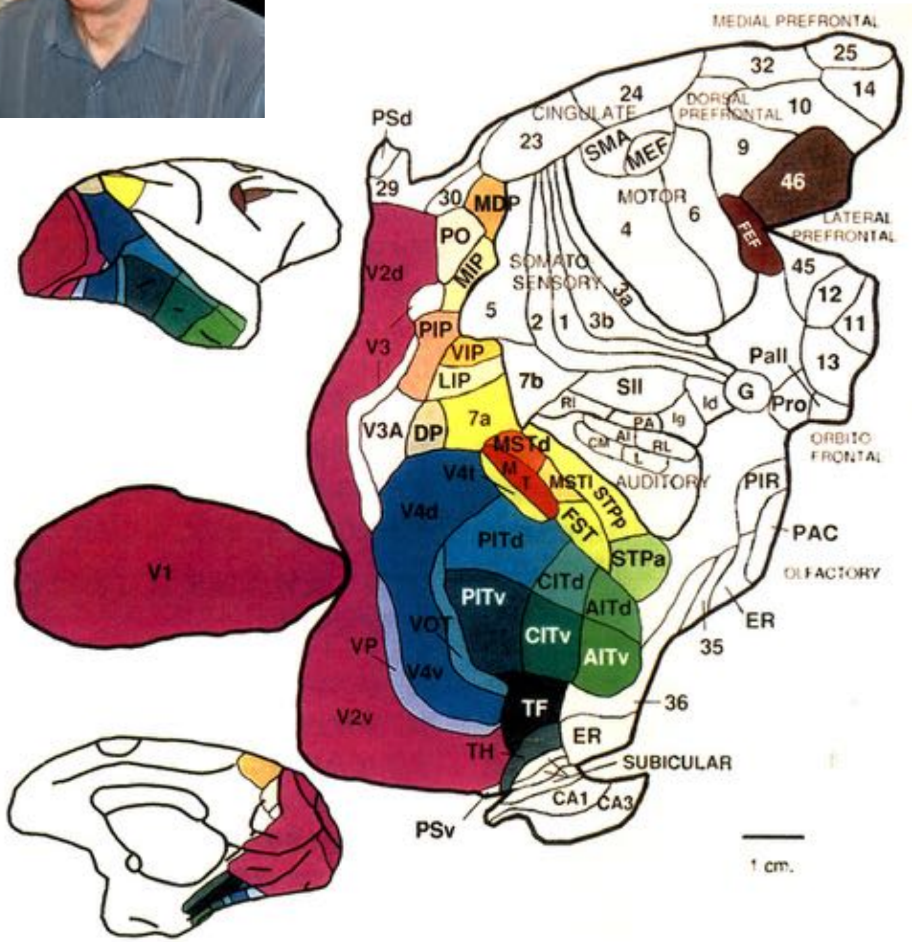
	Macro	Micro
Structure	Integration	
Activity		

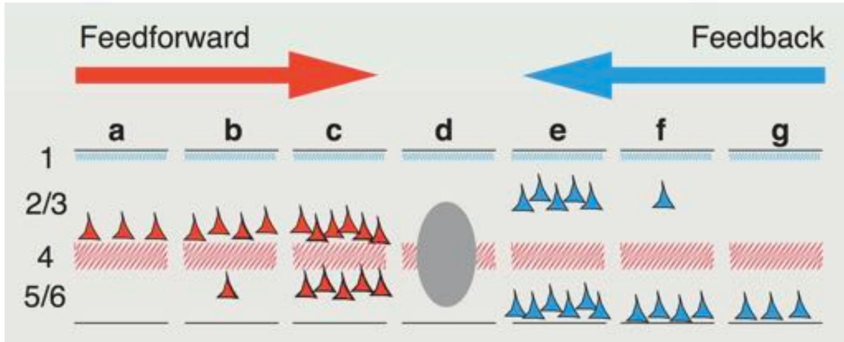


https://sites.google.com/site/tracingneurons/

Circuit diagram of macaque brain

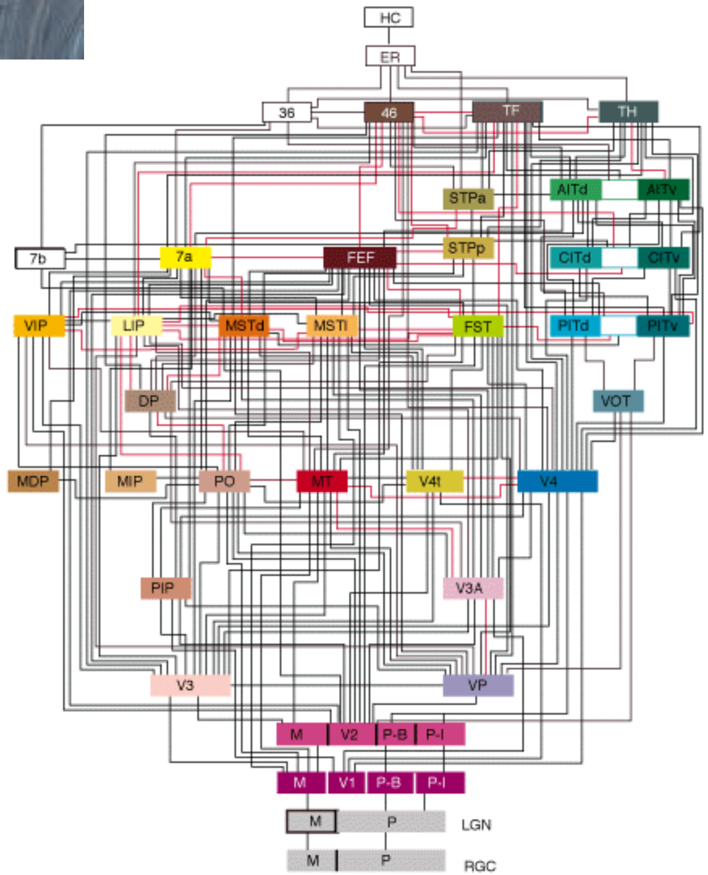
Felleman-Essen's route map

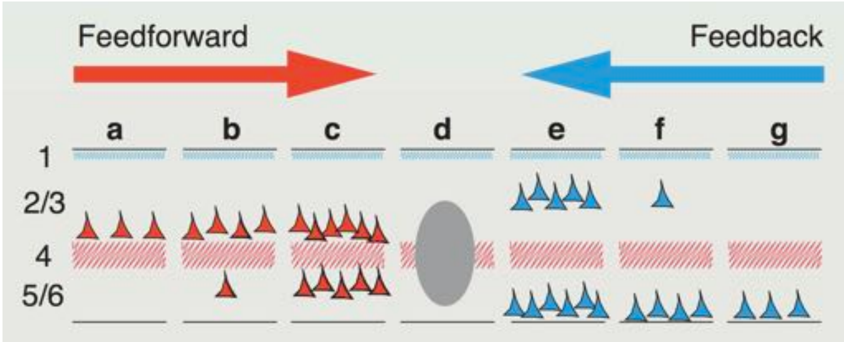




Circuit diagram of macaque brain

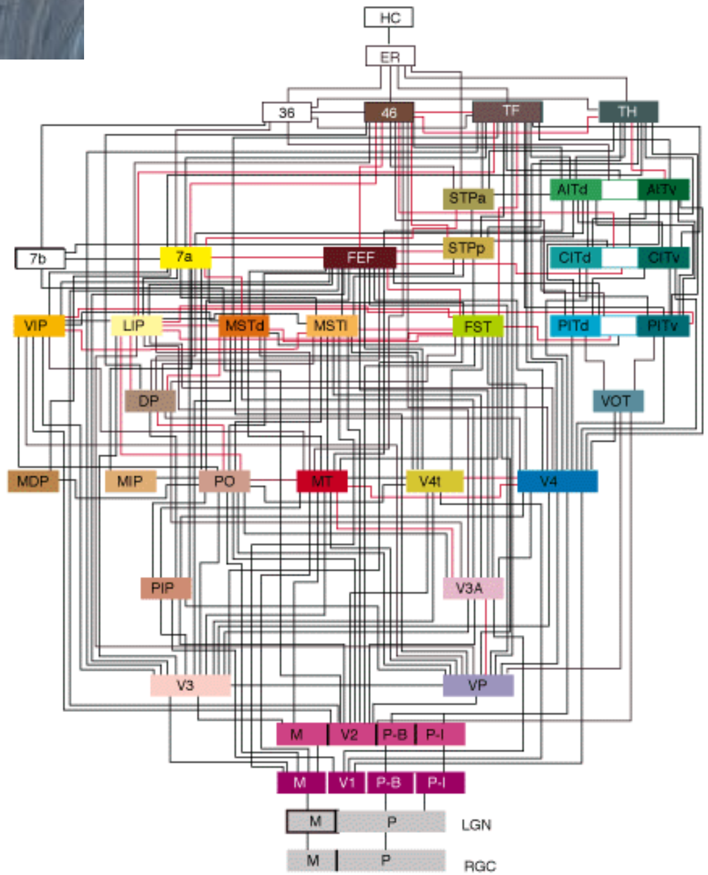
Felleman-Essen's route map

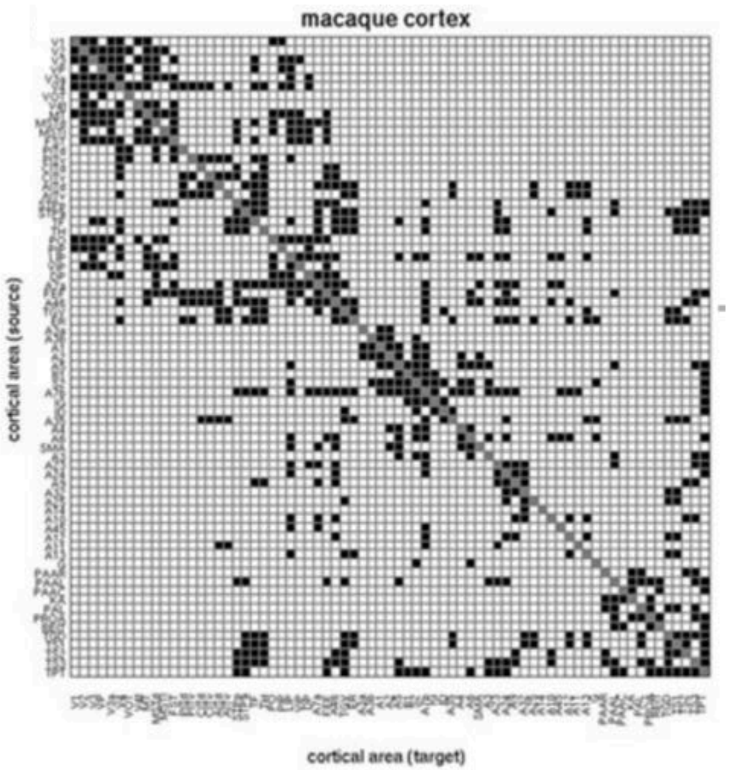




Circuit diagram of macaque brain

Felleman-Essen's route map

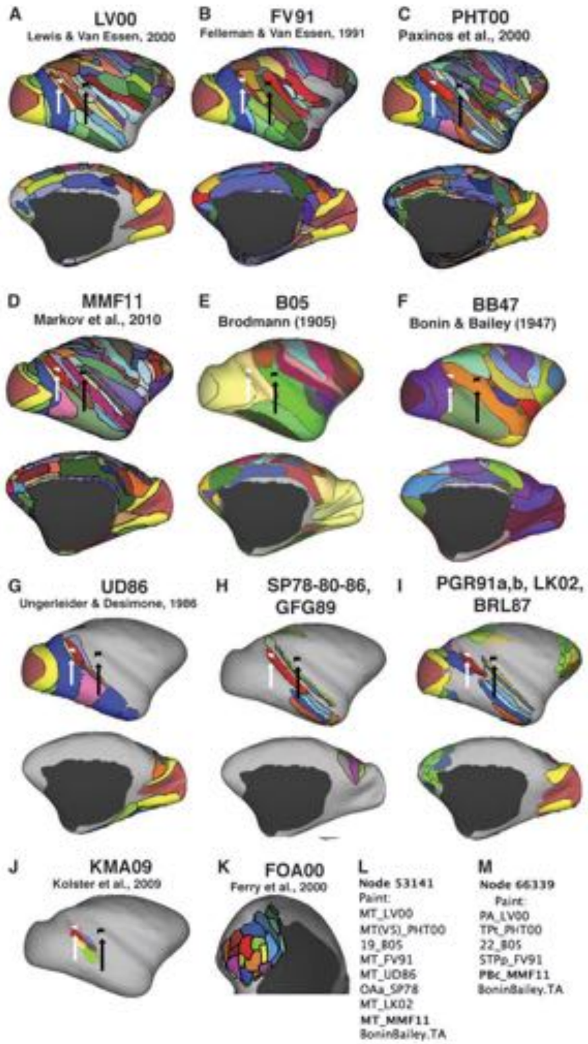


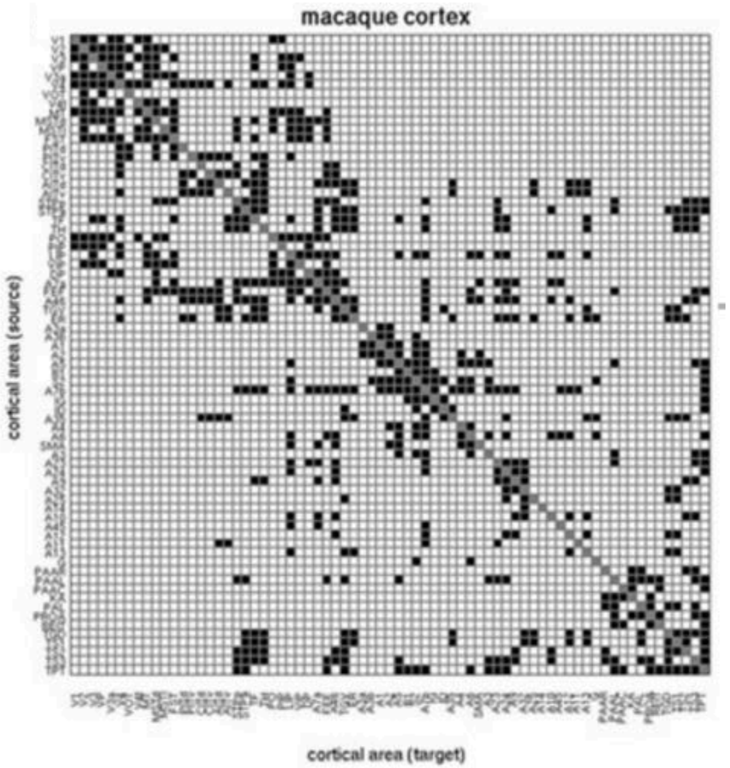


Felleman, Essen (1991) Cerebral Cortex

Circuit diagram of macaque brain

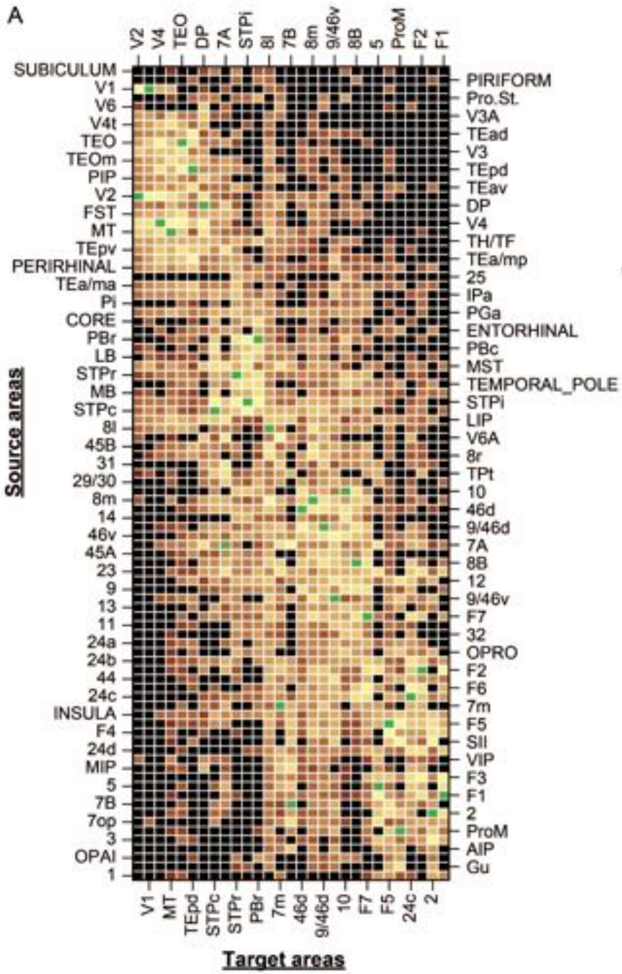
Felleman-Essen's route map

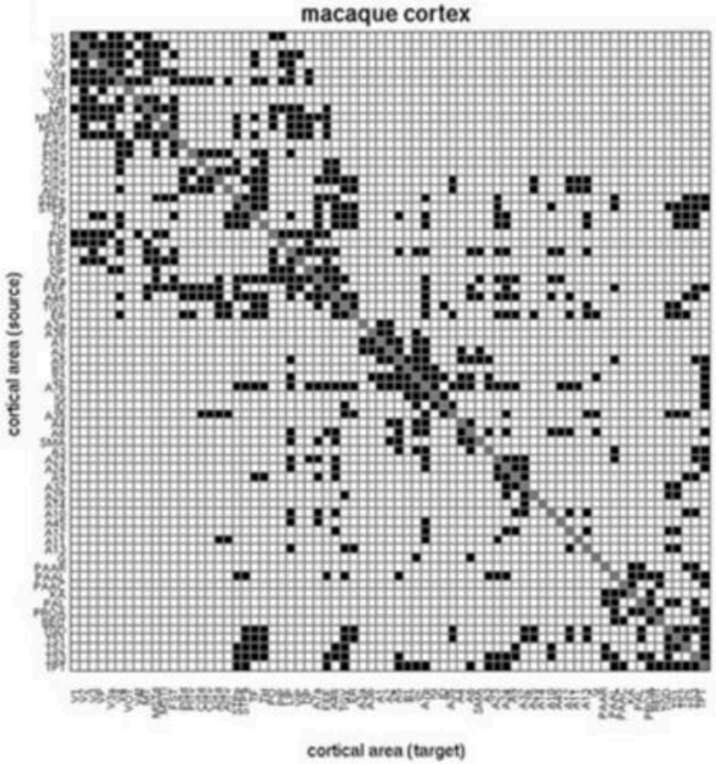




Circuit diagram of macaque brain

Route maps





Informatics approach

	Macro	Micro
Structure	Integration	
Activity		

Rolf Kötter (1961–2010)

Didicated for building CoCoMac database

Complihesive Connectivity database of Monkey brains

https://neuroscimed.wordpress.com/2014/09/21/spatial-temporal-resolution-plots-for-neuroscience-methods/

Informatics approach

CoCoMac

CoCoMac - Macaque macro connectivity at your fingertips

CoCoMac 2nd edition home page

Home | Search | FAQ | About | Site map

Welcome to the new CoCoMac website (background of the redevelopment). For future developments of this site, see this perspective article.

This site

- Provides full, scriptable open access to the data in CoCoMac. If you use CoCoMac-derived data for your research you must adhere to our citation policy.
- Powers the graphical interface to CoCoMac provided by the Scalable Brain Atlas.
- Sports an extensive search/browse wizard, which automatically constructs complex search queries and lets you further explore the database from the results page.
- Allows you to get your hands dirty, by using the custom SQL query service.
- Displays connectivity data in tabular form, through the axonal projections service.

The legacy site at CoCoMac.org is currently offline, but we are building a Virtual Machine that will enable us to revive the legacy.

CoCoMac 2 was initiated at the Donders Institute for Brain, Cognition and Behaviour, and is currently supported by the German neuroinformatics node and the Computational and Systems Neuroscience group at the Juelich research institute.

JÜLICH G-Node

Neuroinformatics

ISSN 1539-2791/04/127–144/$25.00

Original Article

Online Retrieval, Processing, and Visualization of Primate Connectivity Data From the CoCoMac Database

Rolf Kötter

C. & O. Vogt Brain Research Institute and Institute of Anatomy II, Heinrich Heine University
Düsseldorf, Moorenstr. 5, D-40225 Düsseldorf, Germany

Informatics approach

CoCoMac

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Abstract

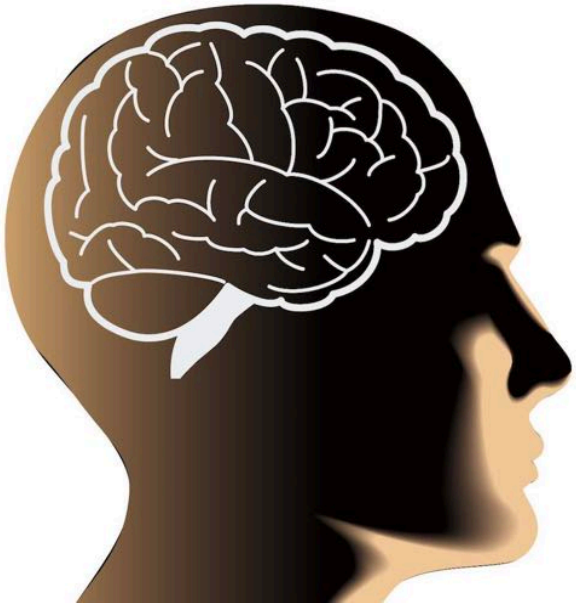
Connectivity is the key to understanding distributed and cooperative brain functions. Detailed and comprehensive data on large-scale connectivity between primate brain areas have been collated systematically from published reports of experimental tracing studies. Although the majority of the data have been made easily available for online retrieval, the multiplicity of brain maps and the precise requirements of anatomical naming limit the intuitive access to the data. The quality of data retrieval can be improved by observing a small set of conventions in data representation. Standardized interfaces open up further opportunities for automated search and retrieval, for flexible visualization of data, and for interoperability with other databases. This article provides a discussion and examples in text and image of the capabilities of the online interface to the CoCoMac database of primate connectivity. These serve to point out sources of potential confusion and failure, and to demonstrate the automated interfacing with other neuroinformatics resources that facilitate selection and processing of connectivity data, for example, for computational modelling and interpretation of functional imaging studies.

Index Entries: Anatomy; cerebral cortex; computer modeling; imaging data analysis; interoperability; macaque; mapping; projections; XML.

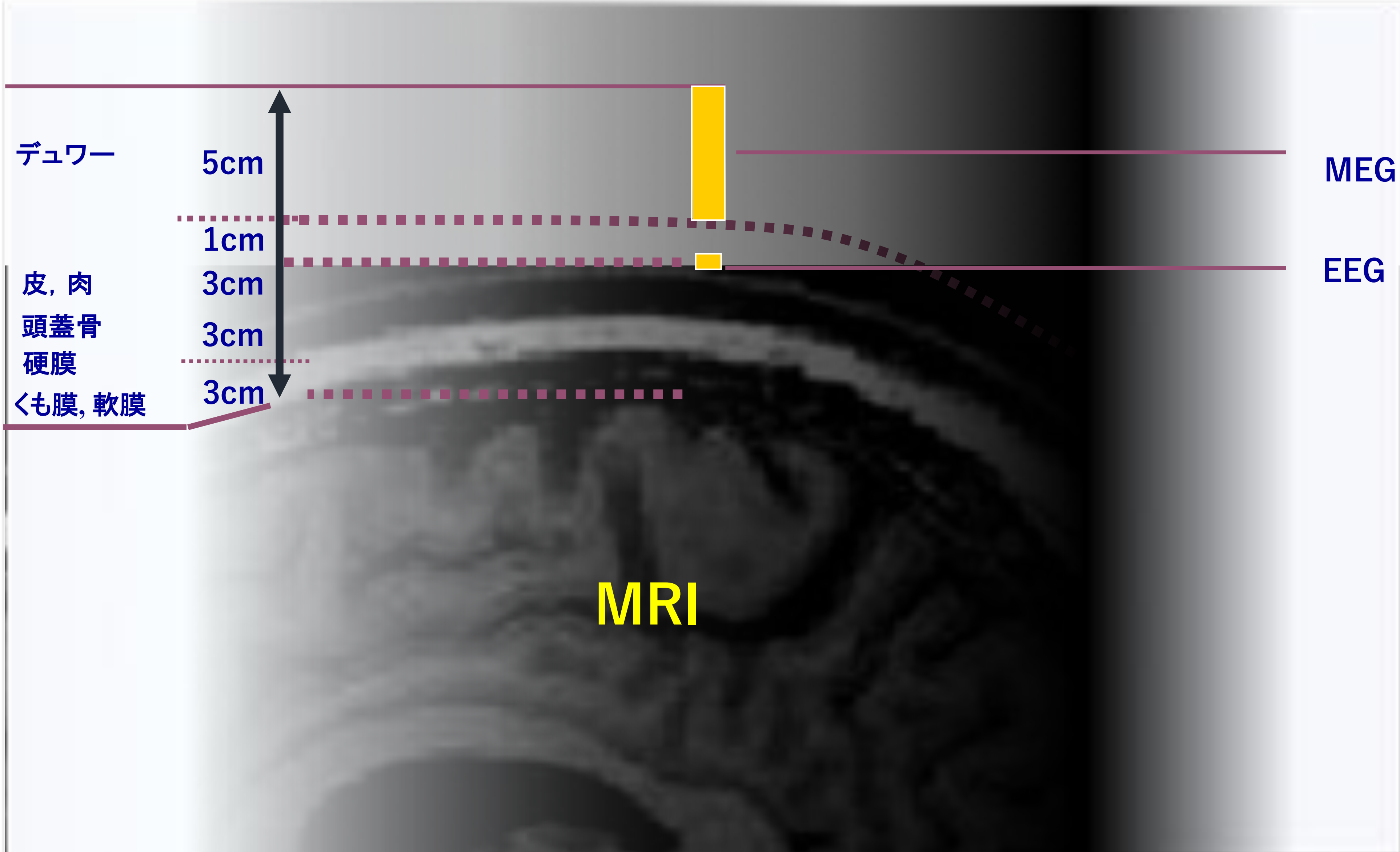
Network data acquisition

	Macro	Micro
Structure	Integration	
Activity		

In the case of Human

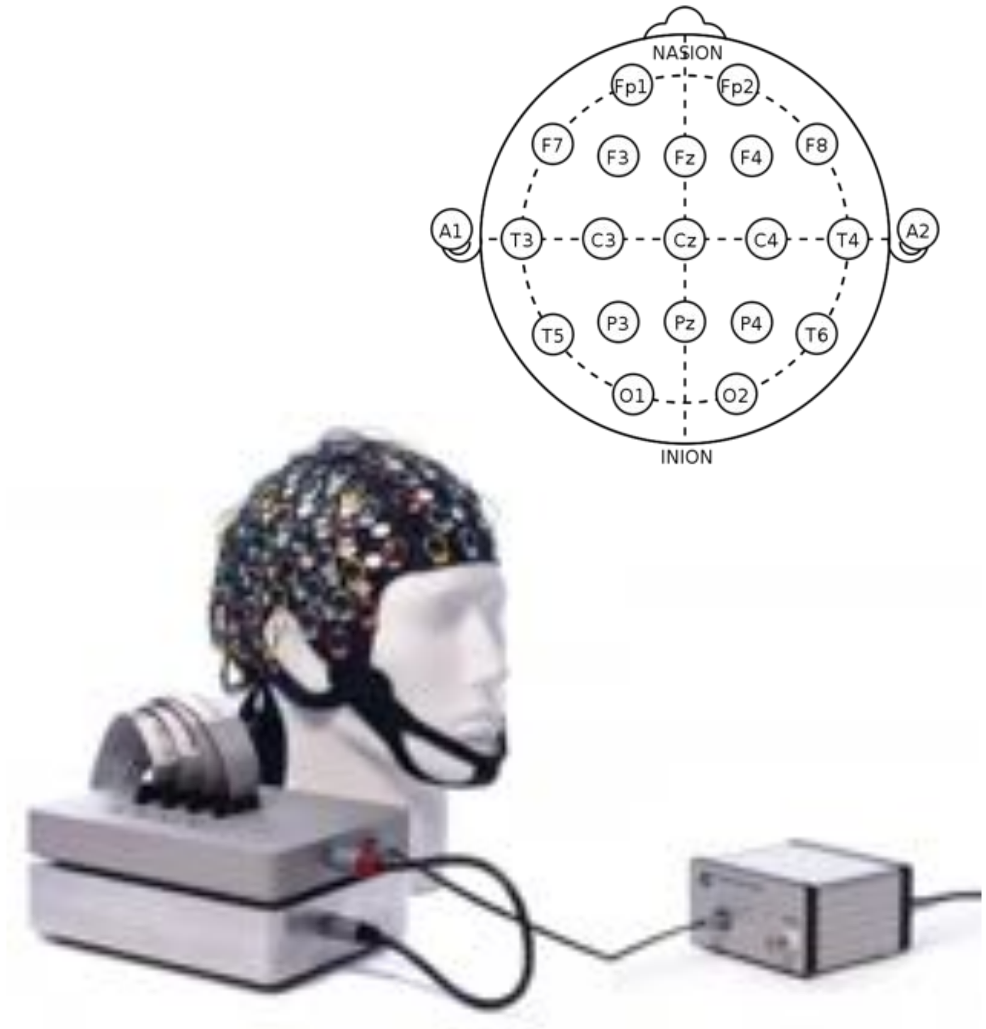


Various brain-recording technologies



Shimono, Hatano (2016)

脳波 (EEG), 脳磁図 (MEG)

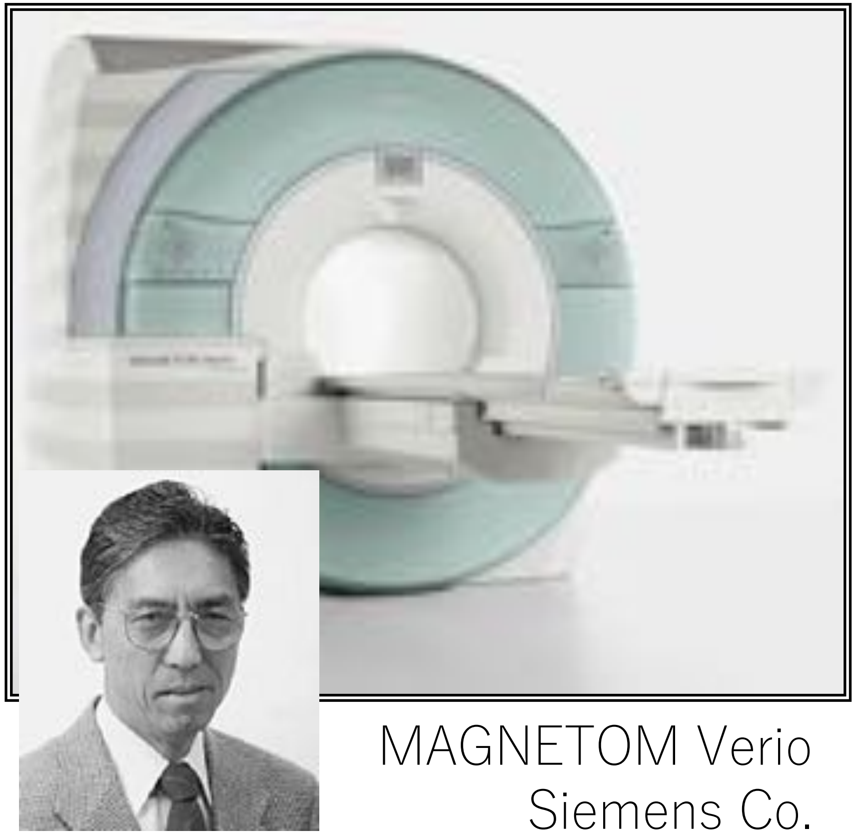


http://www.east-medic.jp/category/eeg/

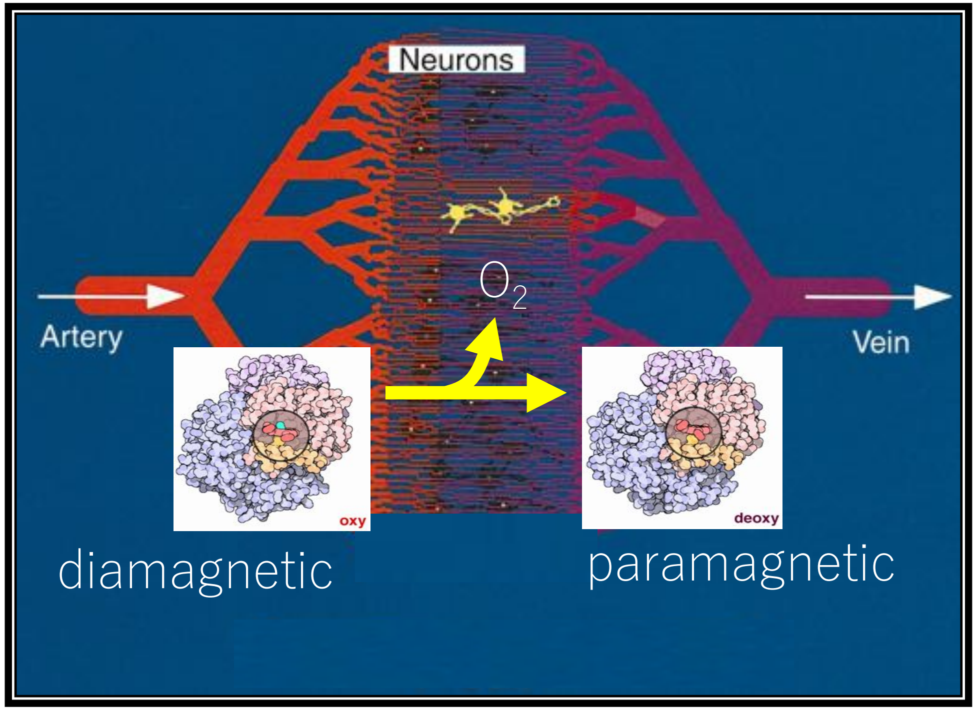
fMRI (functional Magnetic Resonance Imaging)

◆ Mechanism and properties of fMRI

- Recording of metabolic load change (BOLD signal). Ogawa et al. (1990)
- Highest space resolution in noninvasive Neuroimaging technique.



MAGNETOM Verio
Siemens Co.



Menon, Kim TICS (1999)

fMRI ~ Partial effective networks

Network reconstruction from fMRI etc.

Karl Friston (1959–)

https://neuroscimed.wordpress.com/2014/09/21/spatial-temporal-resolution-plots-for-neuroscience-methods/

Three types of networks

■ Structural networks

A set of physical or structural (anatomical) connections linking neural elements (Cajal, 1905; Fellman and Van Essen, 1991).

■ Functional networks

Deviations from statistical independence between distributed and often remote neuronal units (e.g. Gerstein and Perkel, 1969; Singer and Gray, 1995)

■ Effective networks

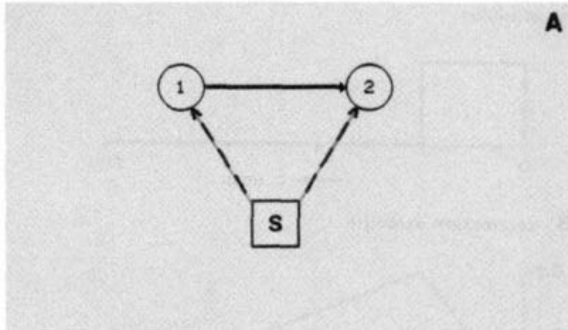
The networks of causal effects between neural elements (Adertsen et al., 1989; Friston, 1994)

Effective networks

JOURNAL OF NEUROPHYSIOLOGY
Vol. 61, No. 5, May 1989. Printed in U.S.A.

Dynamics of Neuronal Firing Correlation: Modulation of "Effective Connectivity"

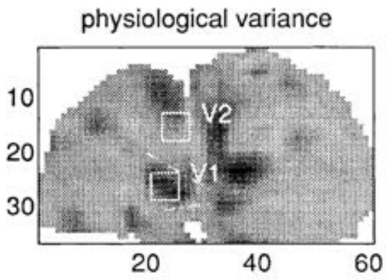
A. M. H. J. AERTSEN, G. L. GERSTEIN, M. K. HABIB, AND G. PALM
(With the Collaboration of P. Gochin and J. Krüger)
Max-Planck-Institute for Biological Cybernetics, D-7400 Tübingen, Federal Republic of Germany; Department of Physiology, University of Pennsylvania, Philadelphia, Pennsylvania 19104-6085; Department of Bio-Statistics, University of North Carolina, Chapel Hill, North Carolina 27514; Vogt-Institute for Brain Research, University of Düsseldorf, D-4000 Düsseldorf, Federal Republic of Germany; Neurlogical Clinic, University of Freiburg, D-7800 Freiburg, Federal Republic of Germany.

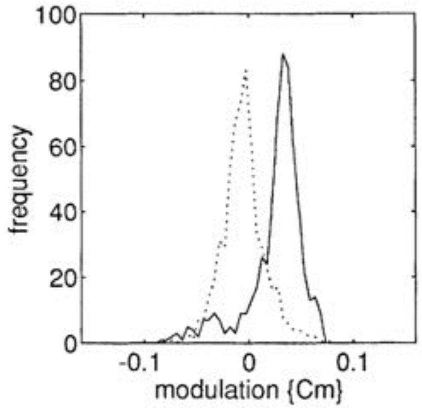


Functional and Effective Connectivity in Neuroimaging: A Synthesis

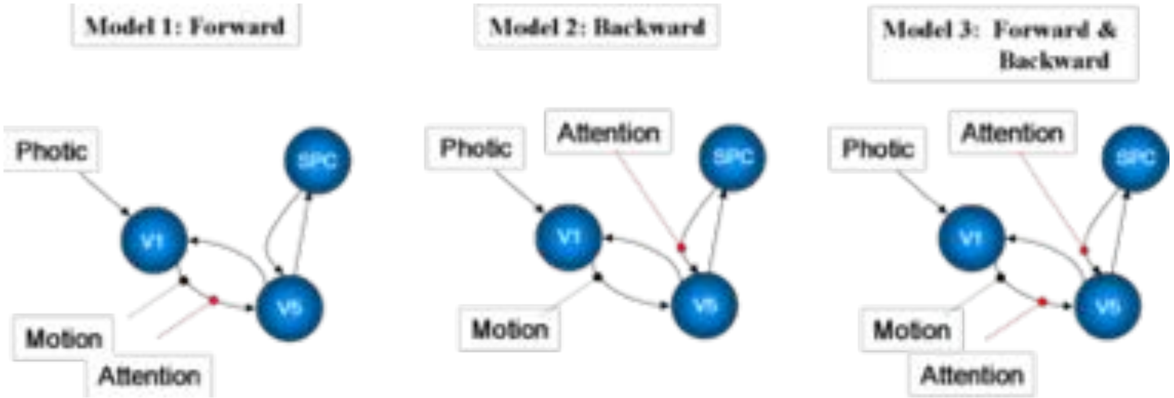
Karl J. Friston

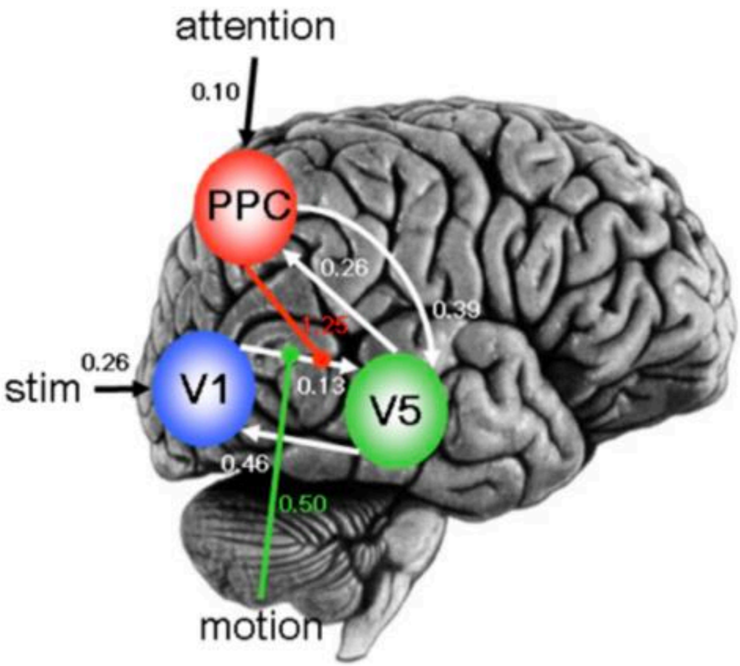
The MRC Cyclotron Unit, Hammersmith Hospital, London, England





fMRI ~ Partial effective networks





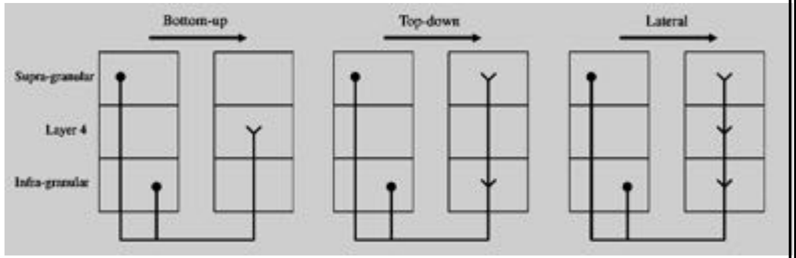
Dynamical Causal Modeling

Karl Friston (1959–)

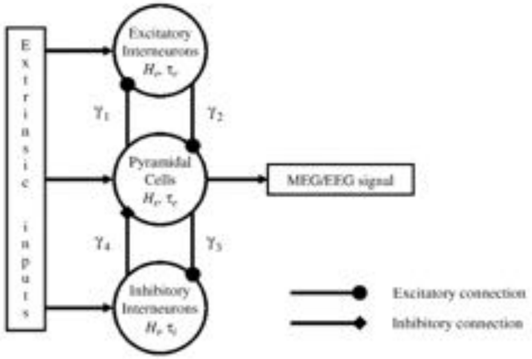
https://neuroscimed.wordpress.com/2014/09/21/spatial-temporal-resolution-plots-for-neuroscience-methods/

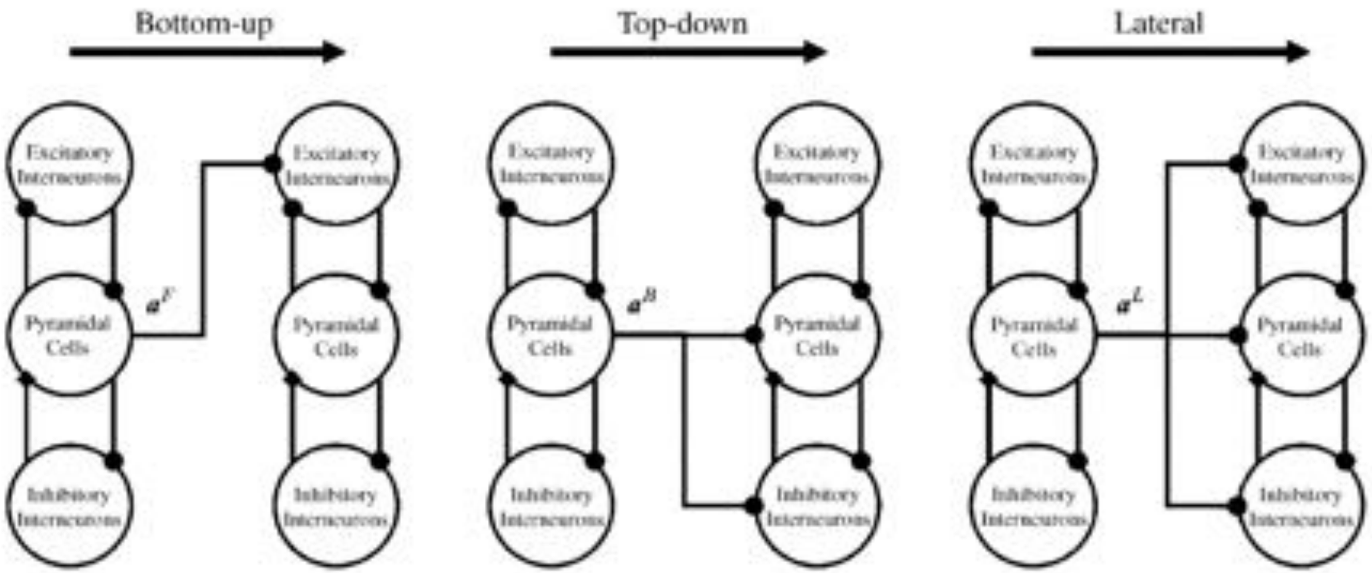
fMRI ~ Partial effective networks

Felleman and Van Essen rules



Jansen's model





https://neuroscimed.wordpress.com/2014/09/21/spatial-temporal-resolution-plots-for-neuroscience-methods/

Background community

BRAIN CONNECTIVITY WORKSHOP

2004 -

Evoked activity
&
Spontaneous activity

Evoked activity & Spontaneous activity

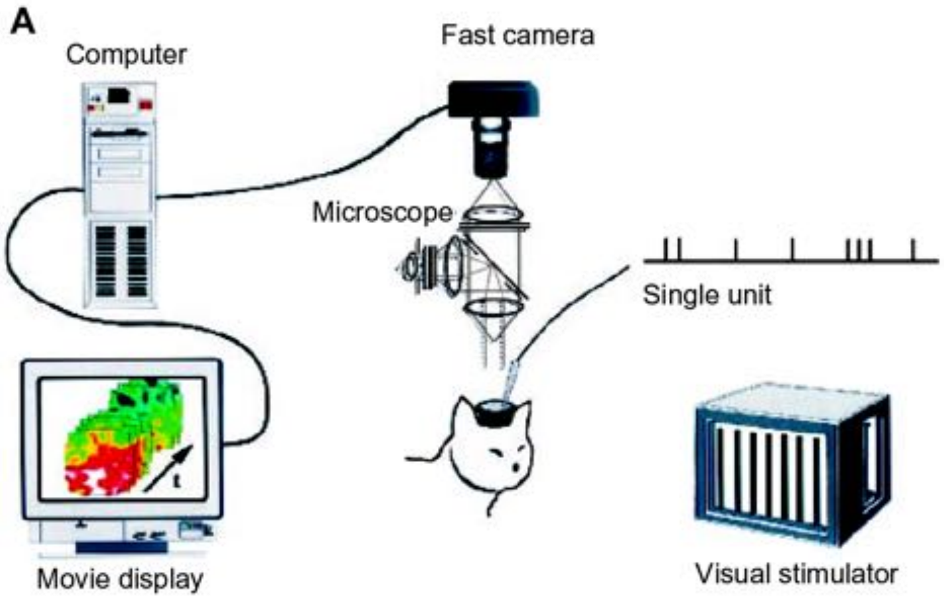
	Macro	Micro
Structure		
Activity		

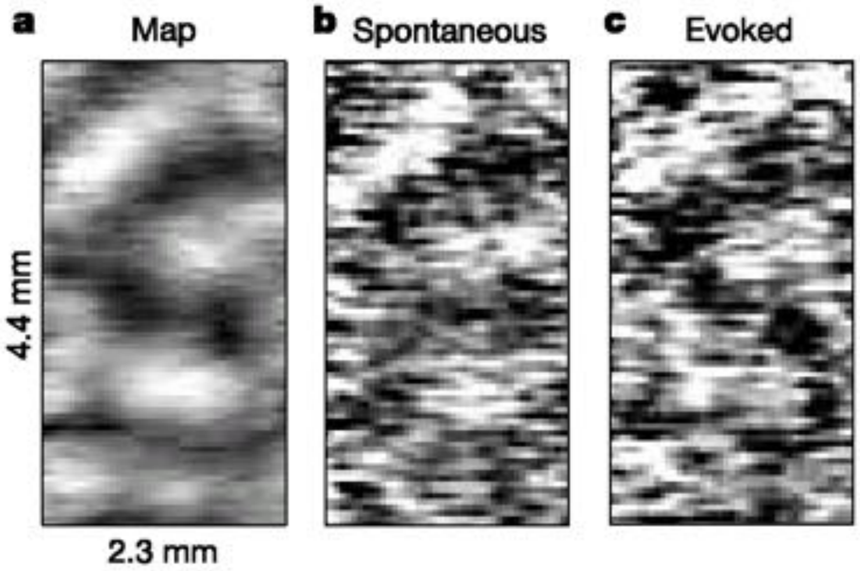
Linking Spontaneous Activity of Single Cortical Neurons and the Underlying Functional Architecture

M. Tsodyks, T. Kenet, A. Grinvald,* A. Arieli

Spontaneously emerging cortical representations of visual attributes

Tal Kenet*, Dmitri Bibitchkov, Misha Tsodyks, Amiram Grinvald & Amos Arieli



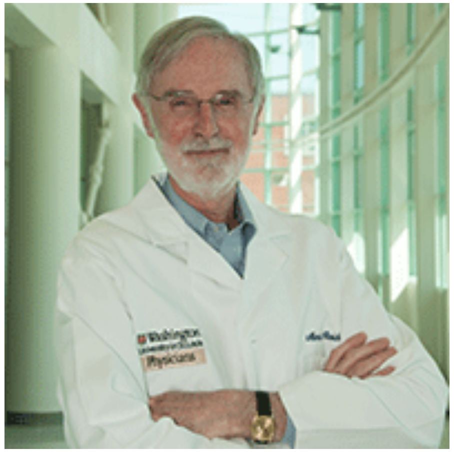


Arieli (1996) Science

Evoked activity & Spontaneous activity

	Macro	Micro
Structure		
Activity		

- **Default Mode Network – macroscopic spontaneous activity**



The Brain's Dark Energy

Marcus E. Raichle

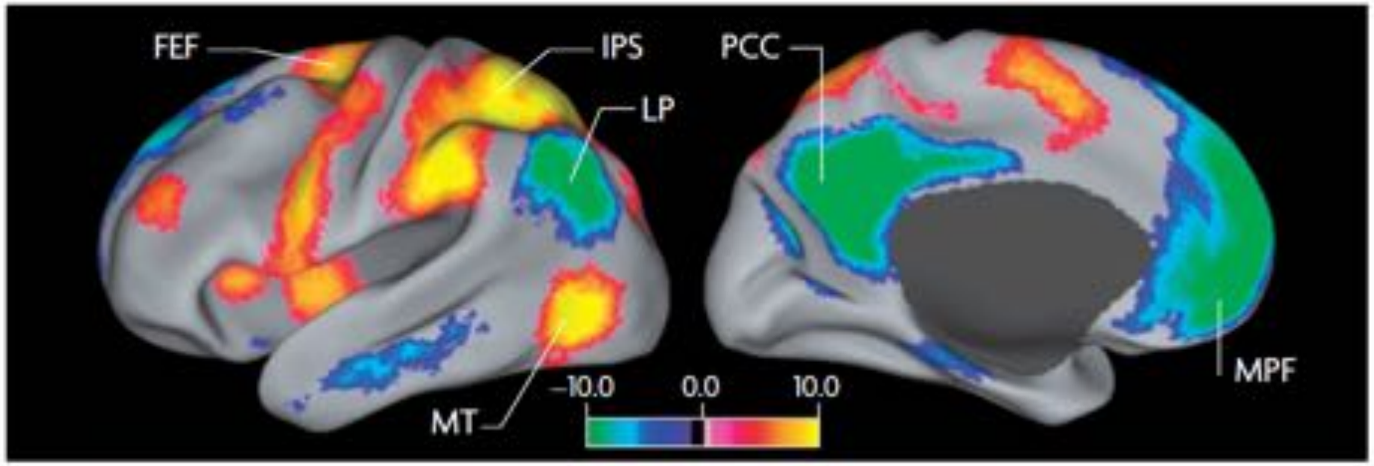


Figure 3 | **Intrinsically defined anticorrelated networks in the human brain.**

How to meet with Default Mode Network?

1. Measurement technique = fMRI
2. Defined as spatially correlated patterns
3. Frequency < 0.1 [Hz]

The Human Connectome Project

What is Connectome?

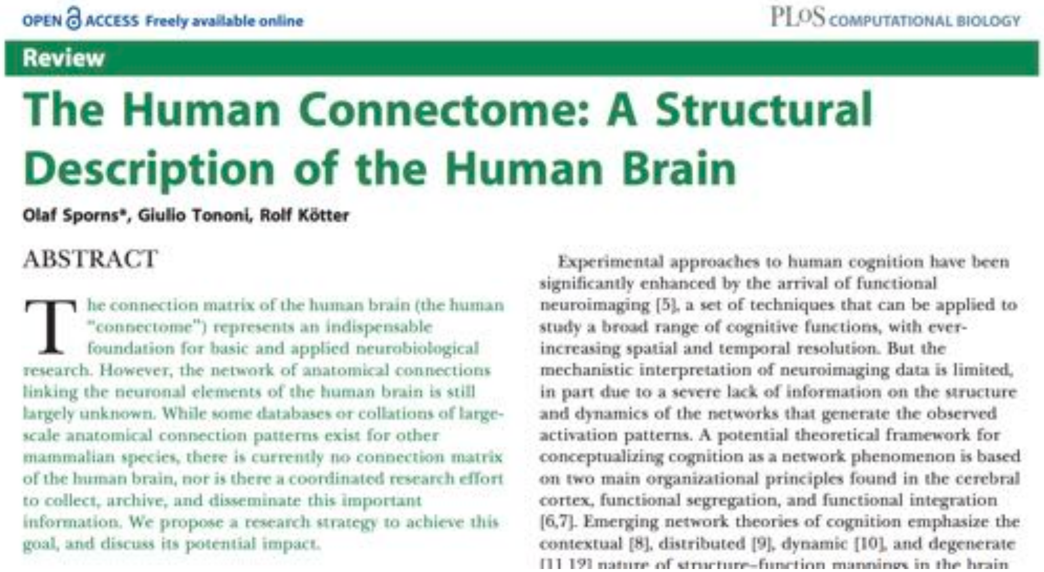
Human Connectome

	Macro	Micro
Structure	S & I	
Activity		

Human Connectome

- Producing the whole brain networks
- Function(fMRI, Default mode) & Structure (DTI)

Olaf Sporns


OPEN ACCESS Freely available online

PLoS COMPUTATIONAL BIOLOGY

Review

The Human Connectome: A Structural Description of the Human Brain

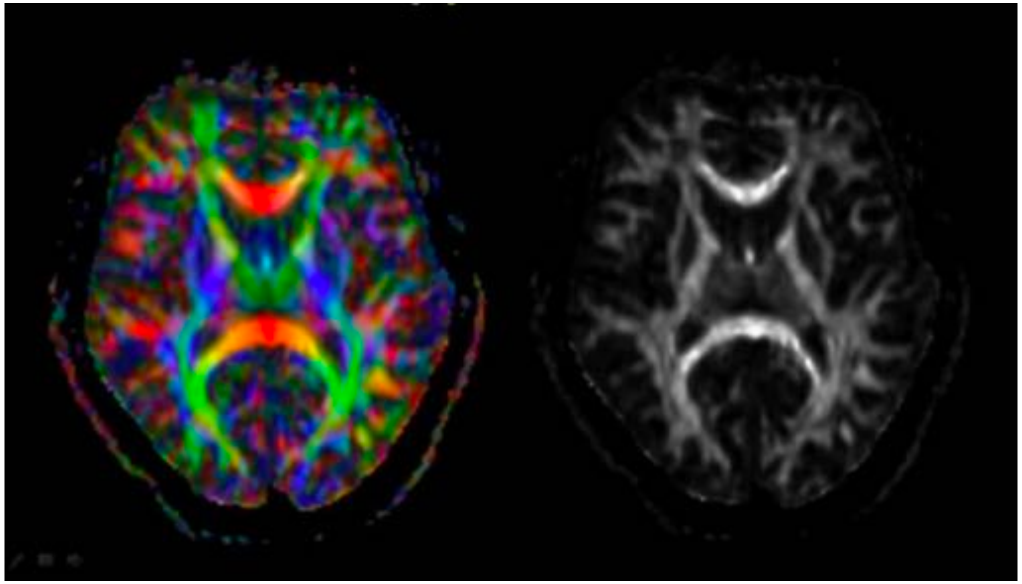
Olaf Sporns*, Giulio Tononi, Rolf Kötter

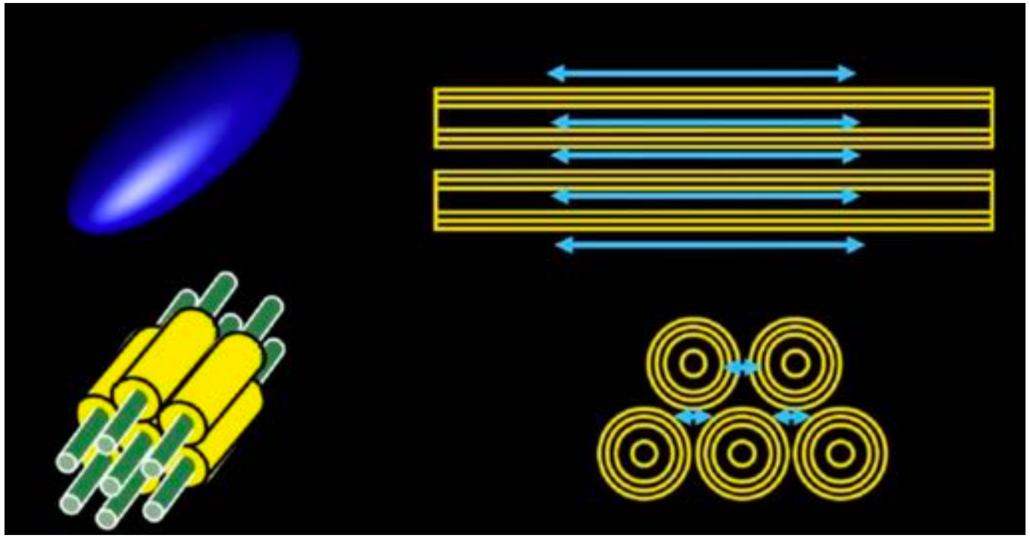
ABSTRACT

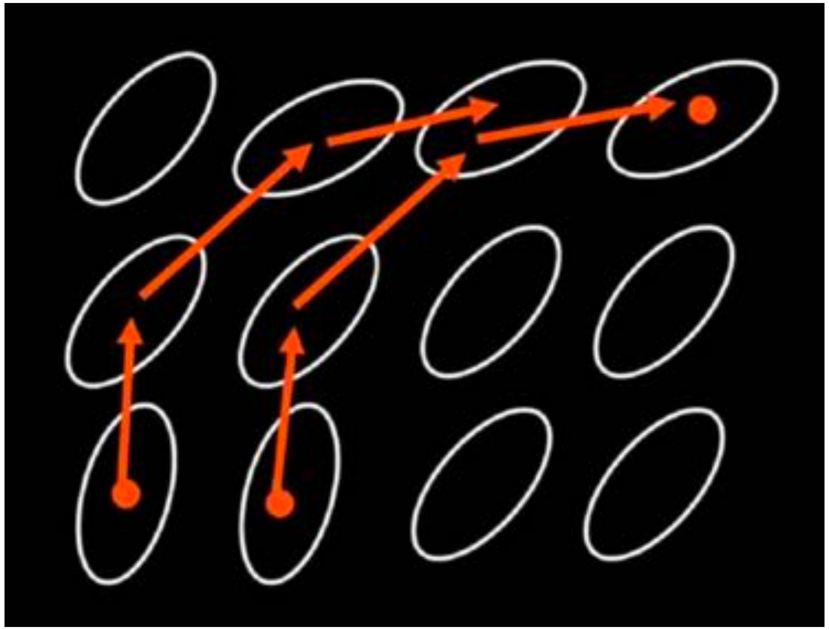
The connection matrix of the human brain (the human "connectome") represents an indispensable foundation for basic and applied neurobiological research. However, the network of anatomical connections linking the neuronal elements of the human brain is still largely unknown. While some databases or collations of large-scale anatomical connection patterns exist for other mammalian species, there is currently no connection matrix of the human brain, nor is there a coordinated research effort to collect, archive, and disseminate this important information. We propose a research strategy to achieve this goal, and discuss its potential impact.

Experimental approaches to human cognition have been significantly enhanced by the arrival of functional neuroimaging [5], a set of techniques that can be applied to study a broad range of cognitive functions, with ever-increasing spatial and temporal resolution. But the mechanistic interpretation of neuroimaging data is limited, in part due to a severe lack of information on the structure and dynamics of the networks that generate the observed activation patterns. A potential theoretical framework for conceptualizing cognition as a network phenomenon is based on two main organizational principles found in the cerebral cortex, functional segregation, and functional integration [6,7]. Emerging network theories of cognition emphasize the contextual [8], distributed [9], dynamic [10], and degenerate [11,12] nature of structure–function mappings in the brain

Diffusion Tensor/Spectram Imaging

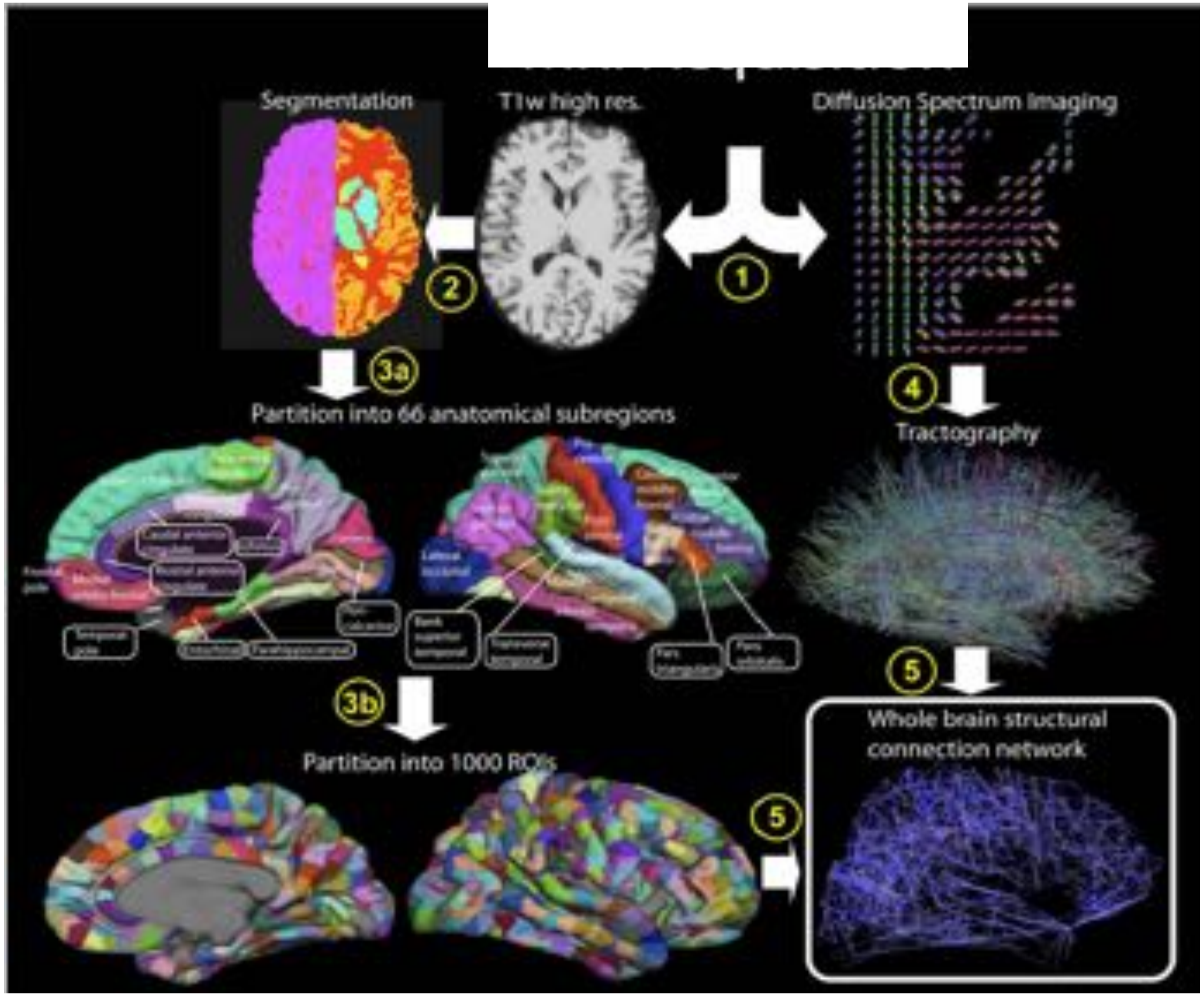






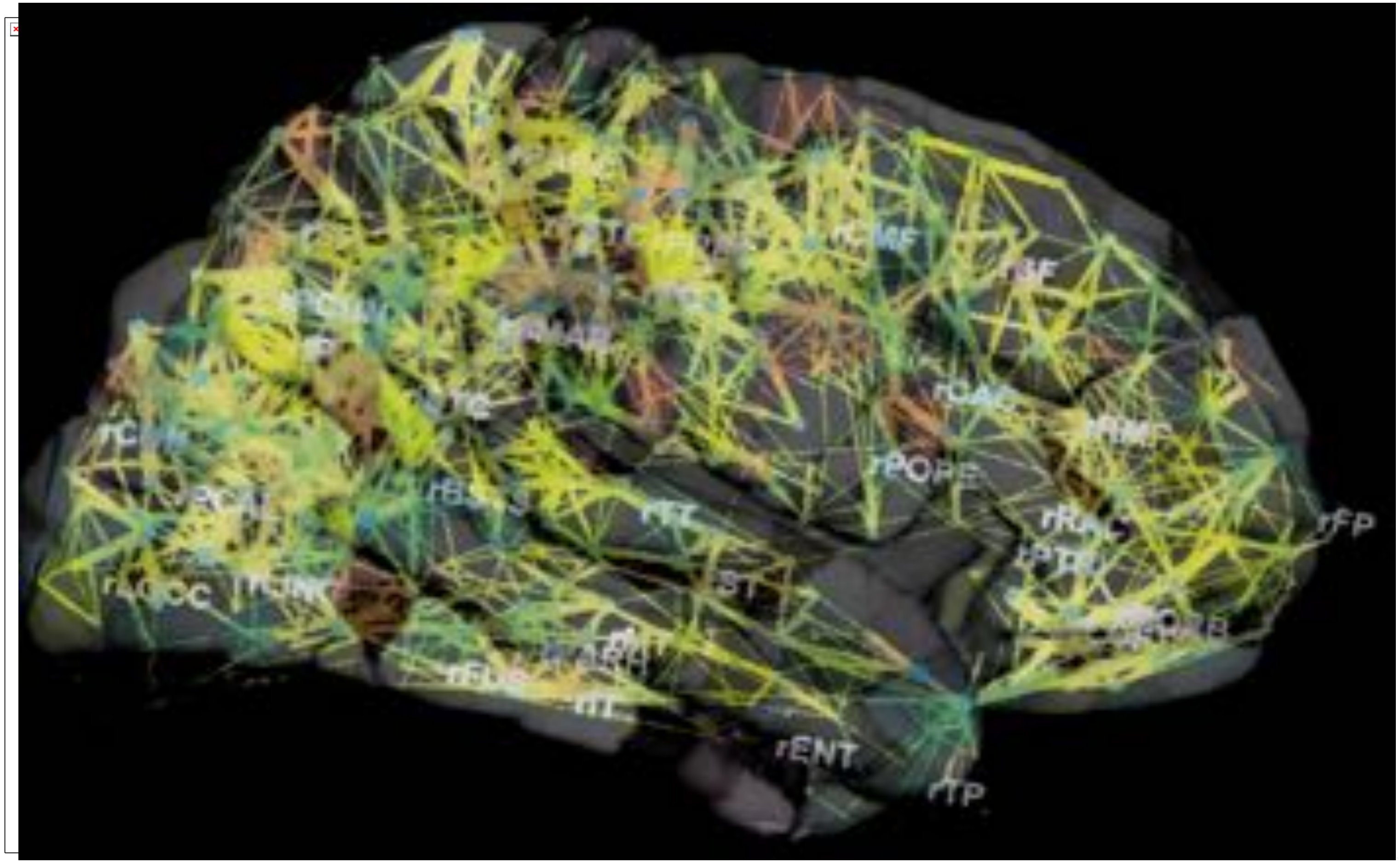
https://www.nobelprize.org/nobel_prizes/medicine/laureates/1963/

Diffusion Tensor Imaging



Hagmann et al. (2008) PLOS Biol.

Diffusion Tensor Imaging



Human Connectome

	Macro	Micro
Structure	S & I	
Activity		

OPEN ACCESS Freely available online PLoS BIOLOGY

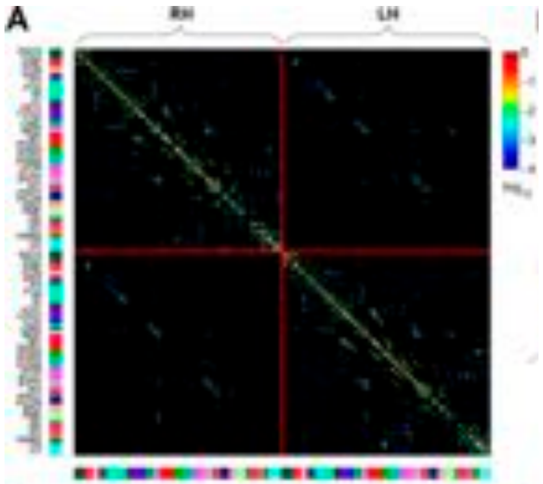
Mapping the Structural Core of Human Cerebral Cortex

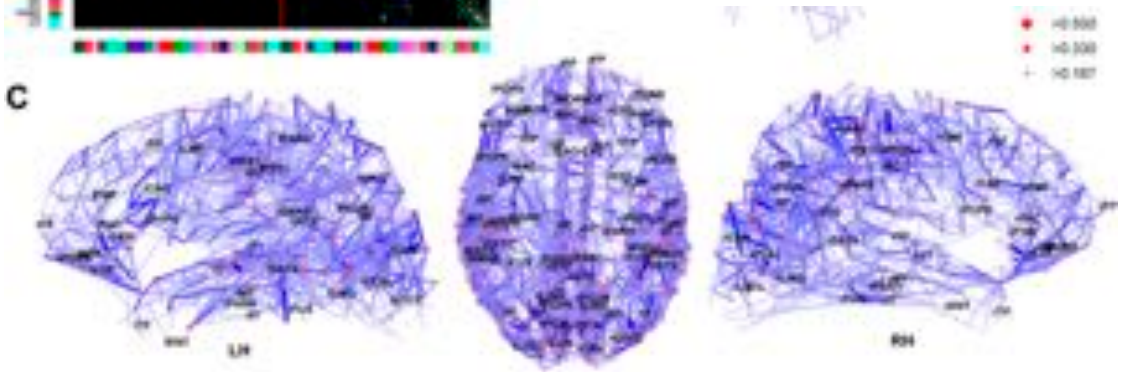
Patric Hagmann[1,2], Leila Cammoun[2], Xavier Gigandet[2], Reto Meuli[1], Christopher J. Honey[3], Van J. Wedeen[4], Olaf Sporns[3*]

1 Department of Radiology, University Hospital Center and University of Lausanne (CHUV), Lausanne, Switzerland, 2 Signal Processing Laboratory (LTS5), Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland, 3 Department of Psychological and Brain Sciences, Indiana University, Bloomington, Indiana, United States of America, 4 Martinos Center for Biomedical Imaging, Department of Radiology, Massachusetts General Hospital and Harvard Medical School, Boston, Massachusetts, United States of America

Structurally segregated and functionally specialized regions of the human cerebral cortex are interconnected by a dense network of cortico-cortical axonal pathways. By using diffusion spectrum imaging, we noninvasively mapped these pathways within and across cortical hemispheres in individual human participants. An analysis of the resulting large-scale structural brain networks reveals a structural core within posterior medial and parietal cerebral cortex, as well as several distinct temporal and frontal modules. Brain regions within the structural core share high degree, strength, and betweenness centrality, and they constitute connector hubs that link all major structural modules. The structural core contains brain regions that form the posterior components of the human default network. Looking both within and outside of core regions, we observed a substantial correspondence between structural connectivity and resting-state functional connectivity measured in the same participants. The spatial and topological centrality of the core within cortex suggests an important role in functional integration.

Citation: Hagmann P, Cammoun L, Gigandet X, Meuli R, Honey CJ, et al. (2008) Mapping the structural core of human cerebral cortex. PLoS Biol 6(7): e159. doi:10.1371/journal.pbio.0060159





Hagmann et al. (2008) PLOS Biol

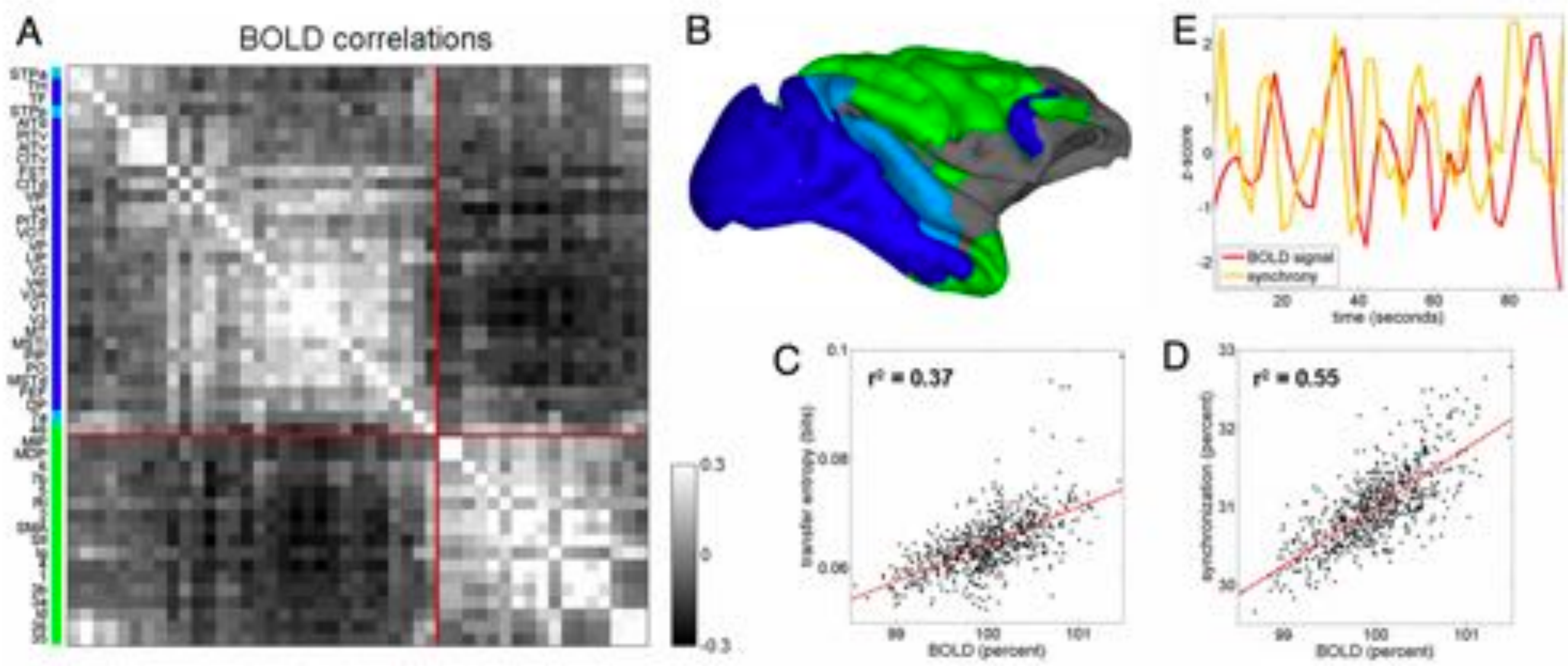
Structure & function

	Macro	Micro
Structure	S & I	
Activity		

Network structure of cerebral cortex shapes functional connectivity on multiple time scales

Christopher J. Honey*, Rolf Kötter[†‡], Michael Breakspear[§], and Olaf Sporns*[¶]

*Department of Psychological and Brain Sciences, Indiana University, Bloomington, IN 47405; [†]Department of Cognitive Neuroscience, Section of Neurophysiology and Neuroinformatics, Radboud University Medical Center, 6500 HB, Nijmegen, The Netherlands; [‡]Cecile and Oskar Vogt Brain Research Institute and Institute of Anatomy II, Heinrich Heine University, Moorenstrasse 5, D-40225 Düsseldorf, Germany; and [§]School of Psychiatry, University of New South Wales, and The Black Dog Institute, Randwick NSW 2031, Australia



Honey et al (2007)

Structure & function

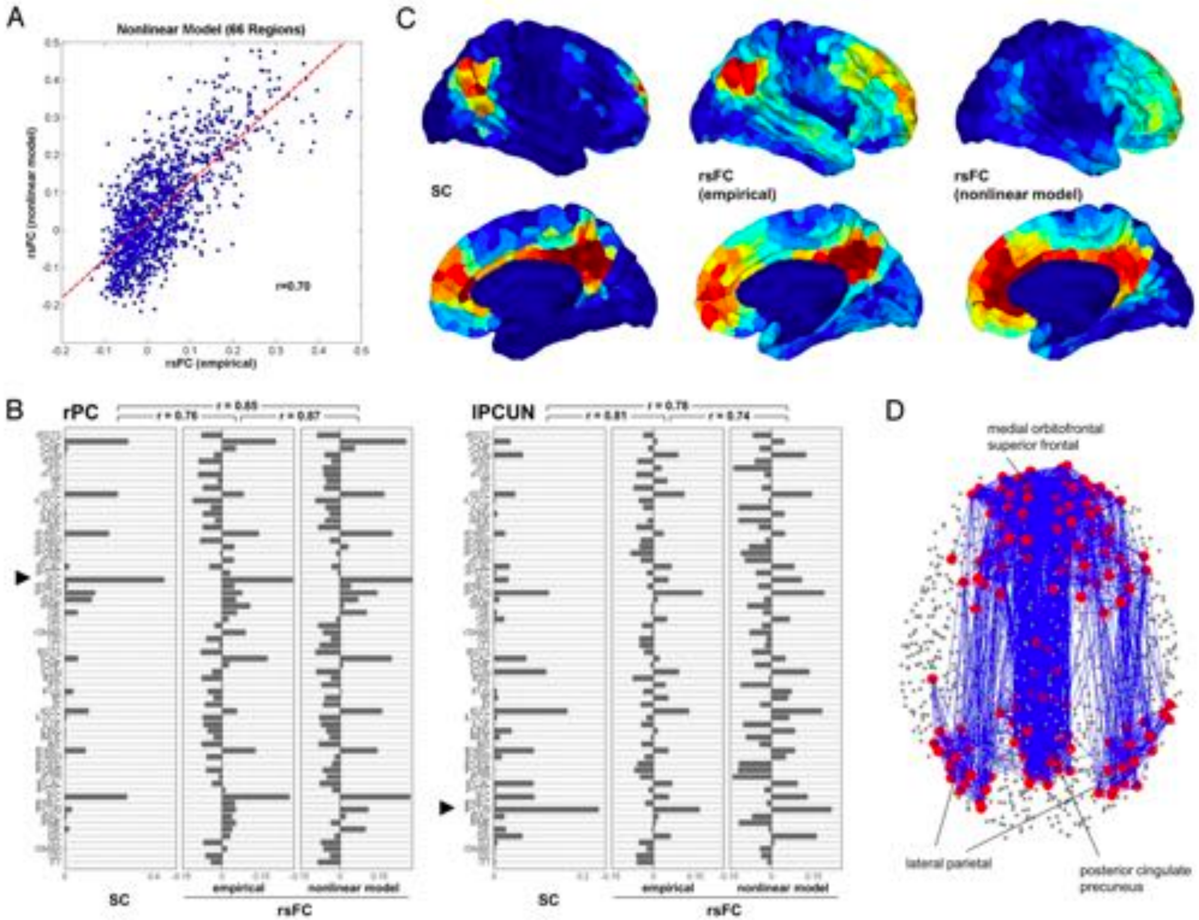
	Macro	Micro
Structure	S & I	
Activity		

Predicting human resting-state functional connectivity from structural connectivity

C. J. Honey[a], O. Sporns[a,1], L. Cammoun[b], X. Gigandet[b], J. P. Thiran[b], R. Meuli[c], and P. Hagmann[b,c]

[a]Department of Psychological and Brain Sciences, Indiana University, Bloomington, IN 47405; [b]Signal Processing Laboratory 5, Ecole Polytechnique Fédérale de Lausanne, CH-1011 Lausanne, Switzerland; and [c]Department of Radiology, University Hospital Center and University of Lausanne, CH-1011 Lausanne, Switzerland

Edited by Marcus E. Raichle, Washington University, St. Louis, MO, and approved December 9, 2008 (received for review November 4, 2008)

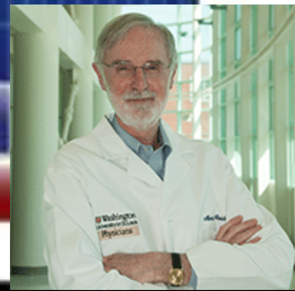


After connectomics

	Macro	Micro
Structure	S & I	
Activity		

NIH Blueprint for Neuroscience R

Home | Research & Funding | Resources & Tools | Training | K-12 Education



The Human Connectome Project

Human Connectome

The NIH Human Connectome Project is an ambitious effort to map the neural pathways that underlie human brain function. The overarching purpose of the Project is to acquire and share data about the structural and functional connectivity of the human brain. It will greatly advance the capabilities for imaging and analyzing brain connections, resulting in improved sensitivity, resolution, and utility, thereby accelerating progress in the emerging field of human connectomics.

Altogether, the Human Connectome Project will lead to major advances in our understanding of what makes us uniquely human and will set the stage for future studies of abnormal brain circuits in many neurological and psychiatric disorders.

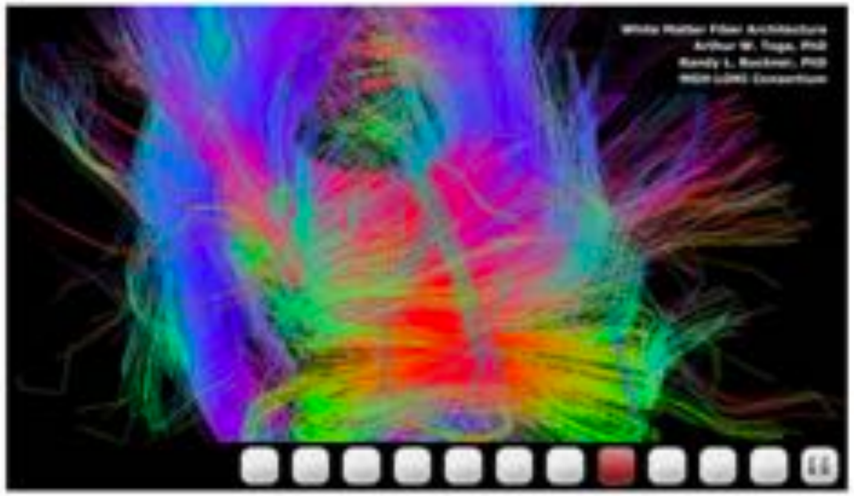
Consortia

The Blueprint has funded two major cooperative agreements that will take complementary approaches to deciphering the brain's complex wiring diagram. For more information see the NIH press release, "$40 million awarded to trace human brain's connections."

Use the box at the right to search the consortium sites or browse the sites directly using the links below.

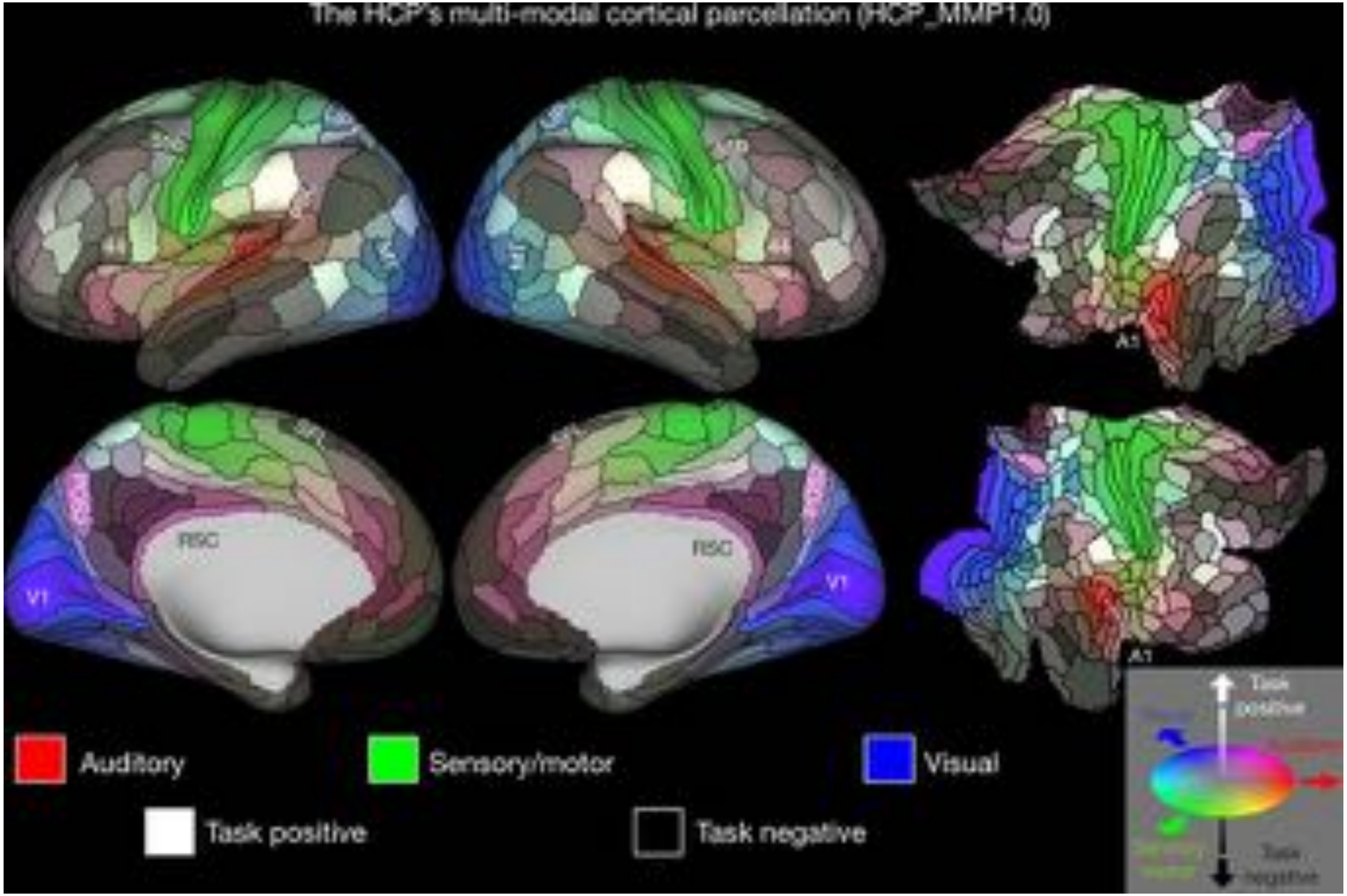
Connectome News and Announcements

- Charlie Rose TV show discusses NY Times HCP articles
  January 6, 2014
- From the NIH Director's Blog: The Symphony Inside Your Brain
  November 5, 2012



http://rstb.royalsocietypublishing.org/content/369/1653.cover-expansion

Brain parcellation map



https://youtu.be/UHDfvfYCY0U

Supplemental history: Pre-connectomics

Network analyses in EEG ?

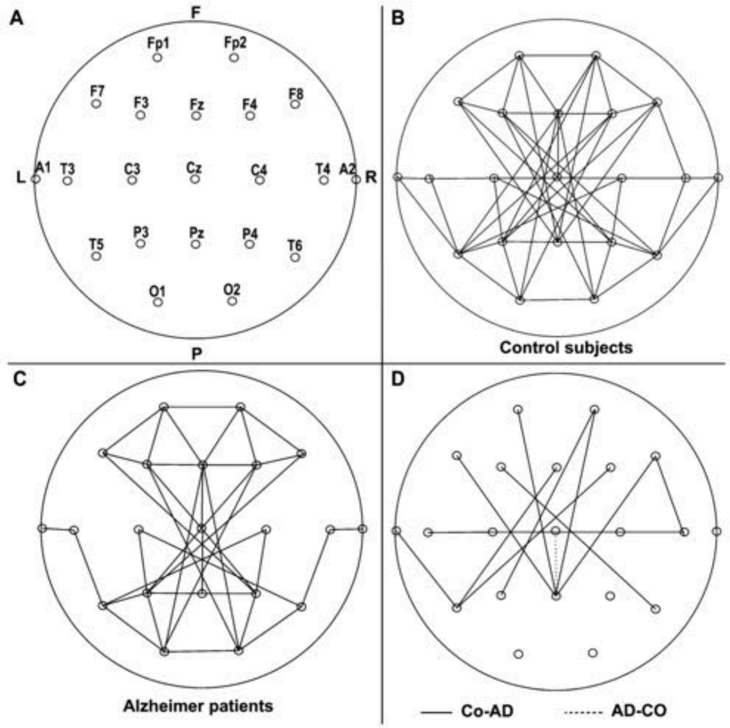
Cerebral Cortex January 2007;17:92-99
doi:10.1093/cercor/bhj127
Advance Access publication February 1, 2006

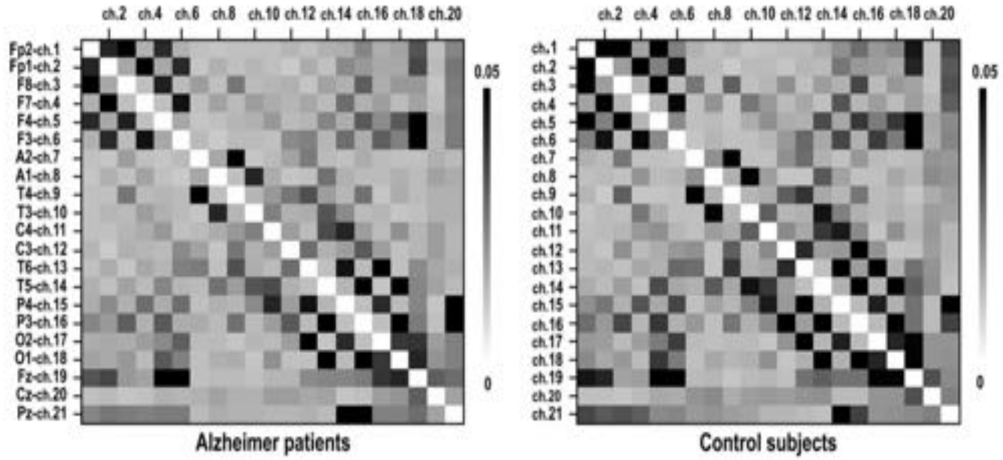
Small-World Networks and Functional Connectivity in Alzheimer's Disease

C. J. Stam[1,2], B. F. Jones[2], G. Nolte[3,4], M. Breakspear[5,6] and Ph. Scheltens[2]

[1]Department of Clinical Neurophysiology, VU University Medical Center, PO Box 7057, 1007 MB Amsterdam, The Netherlands, [2]Alzheimer Center, VU University Medical Center, PO Box 7057, 1007 MB Amsterdam, The Netherlands, [3]Human Motor Control Section, NINDS, National Institutes of Health, 10 Center Drive MSC 1428 Bethesda, MD, USA, [4]Fraunhofer First, Kekulestrae 7, 12489 Berlin, Germany, [5]Brain Dynamics Centre, Westmead Hospital, Westmead, New South Wales 2145, Australia and [6]School of Physics, University of Sydney, Sydney, Australia

The first and second authors have contributed equally to this work





Network data acquisition

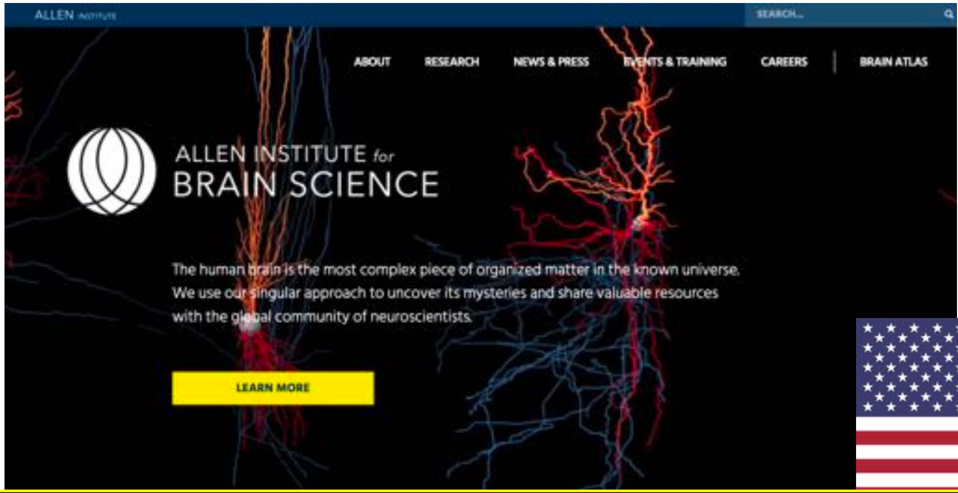
	Macro	Micro
Structure	Integration	
Activity		

In the case of rodent

Circuit diagram of rodent brain

BRAIN Initiative

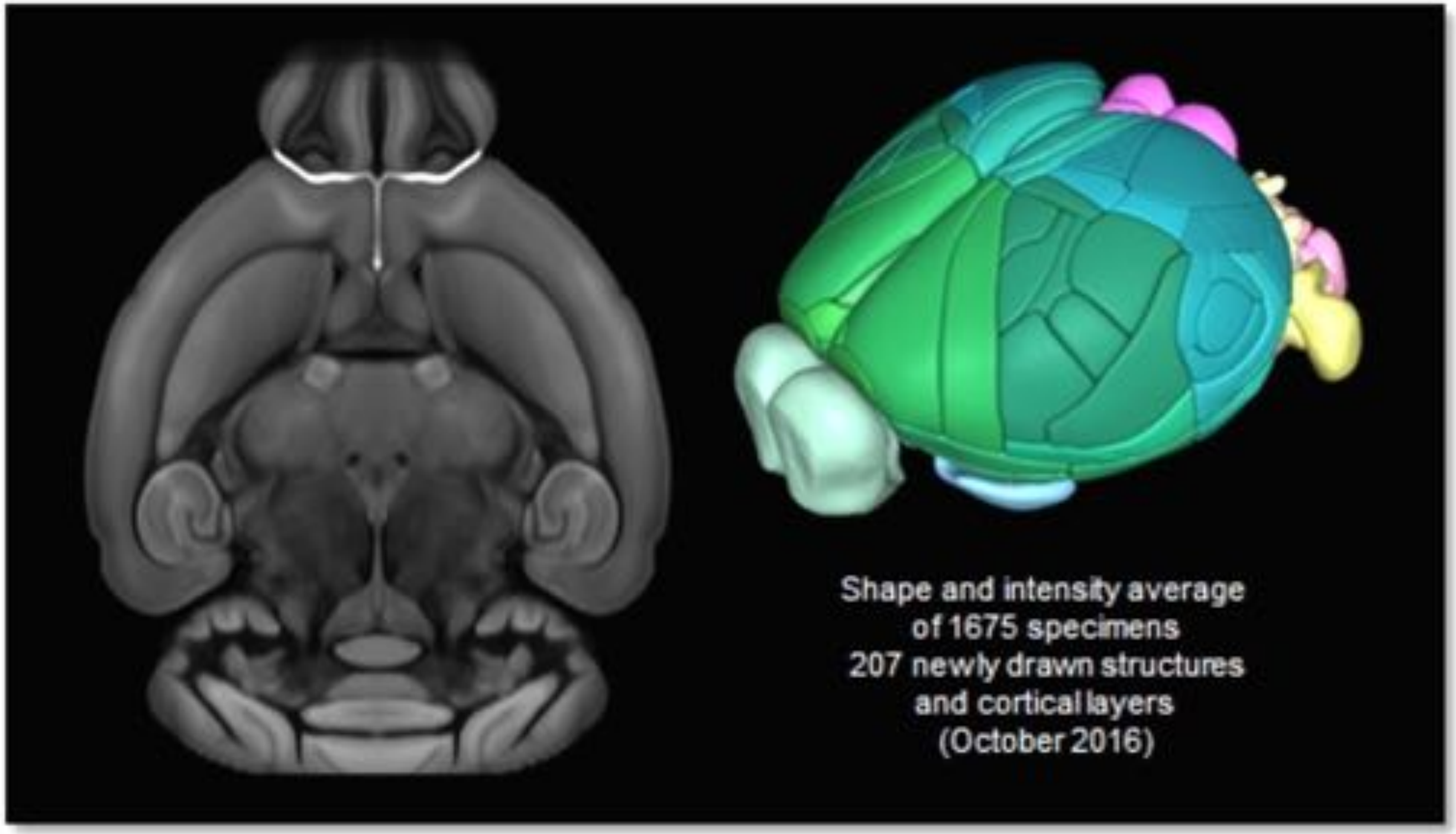
Allen Institute for brain science ∈ BRAIN Initiative



Human Brain project

Circuit diagram of rodent brain

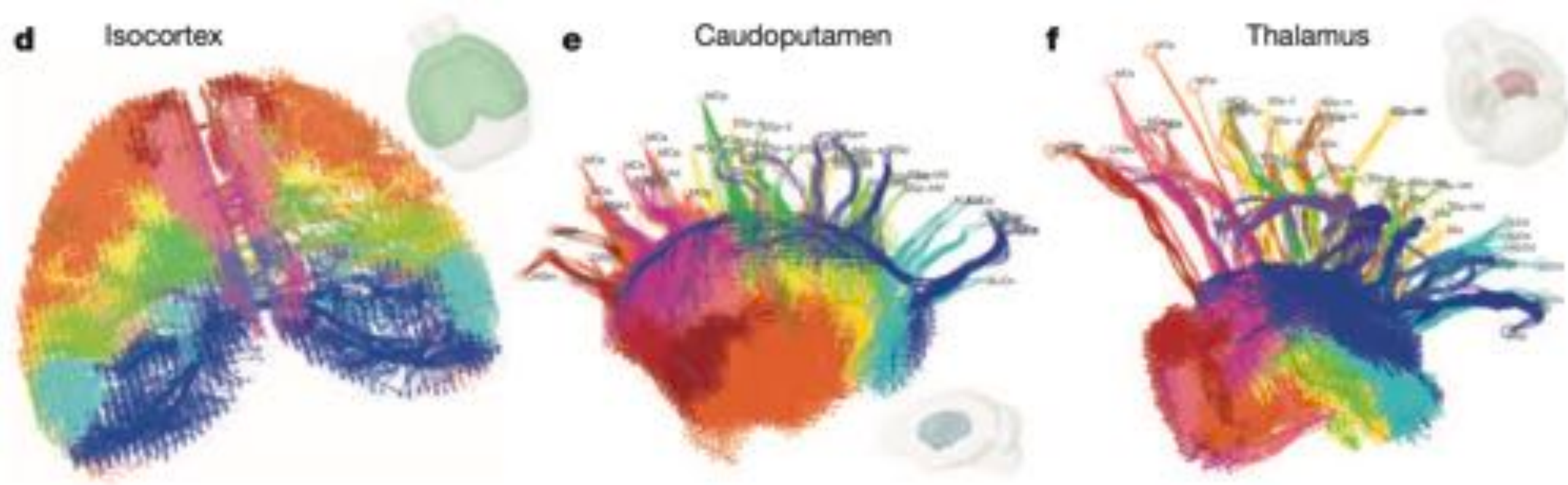
Allen Institute brain atlas



Oh et al. (2014) Nature

Circuit diagram of rodent brain

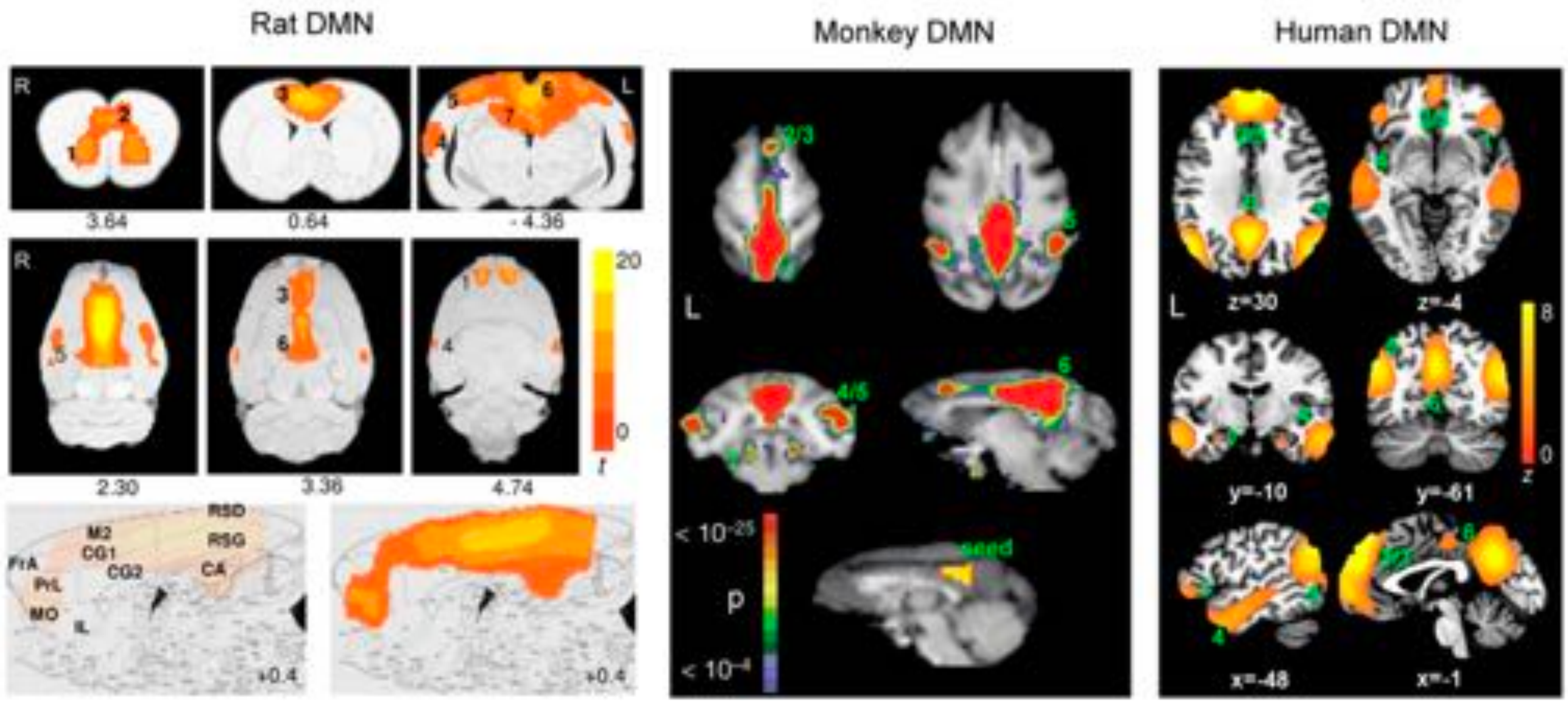
Allen Institute brain atlas



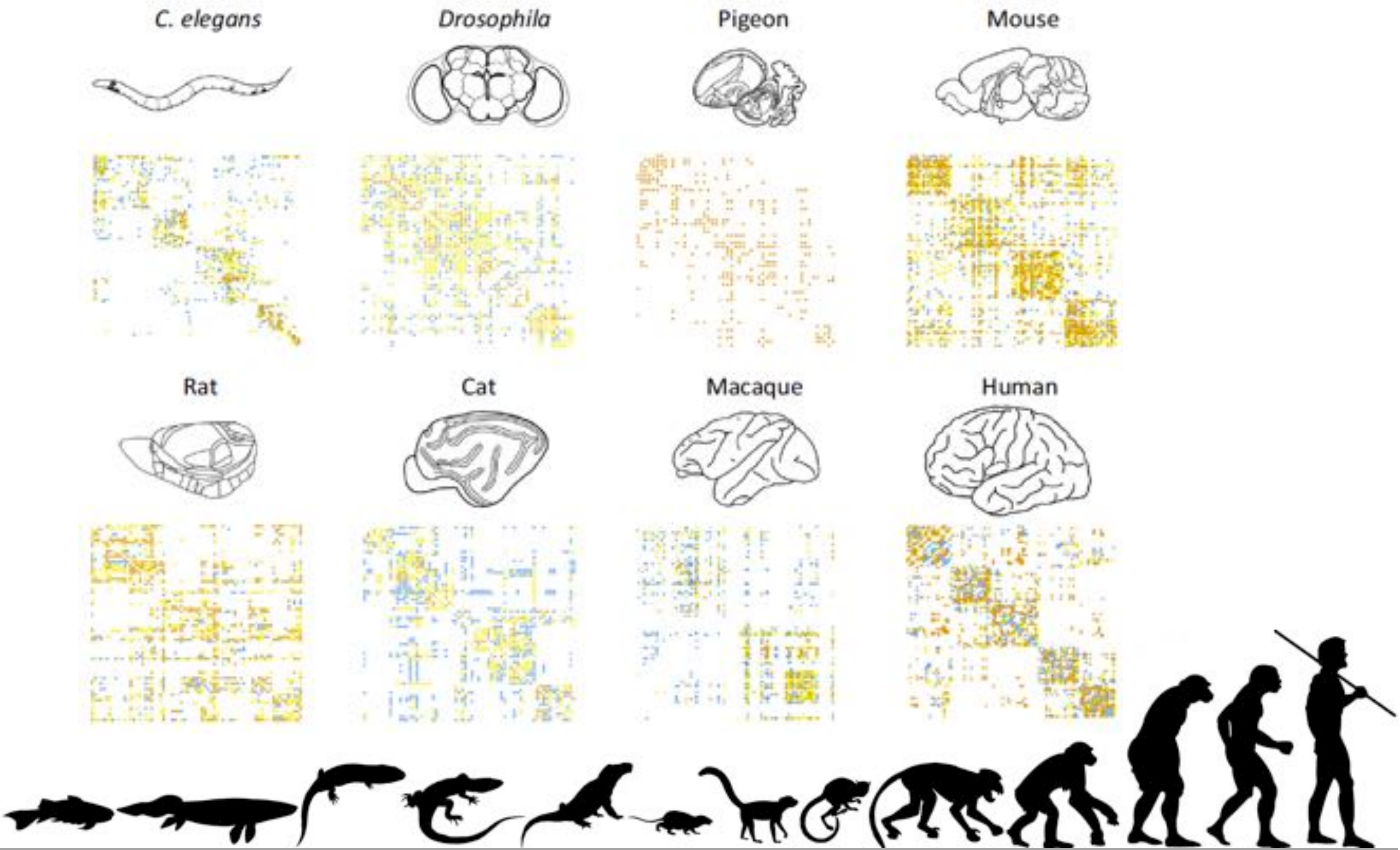
Oh et al. (2014) Nature

Spontaneous activity in fMRI

Default mode network: Rodent, Monkey, Human

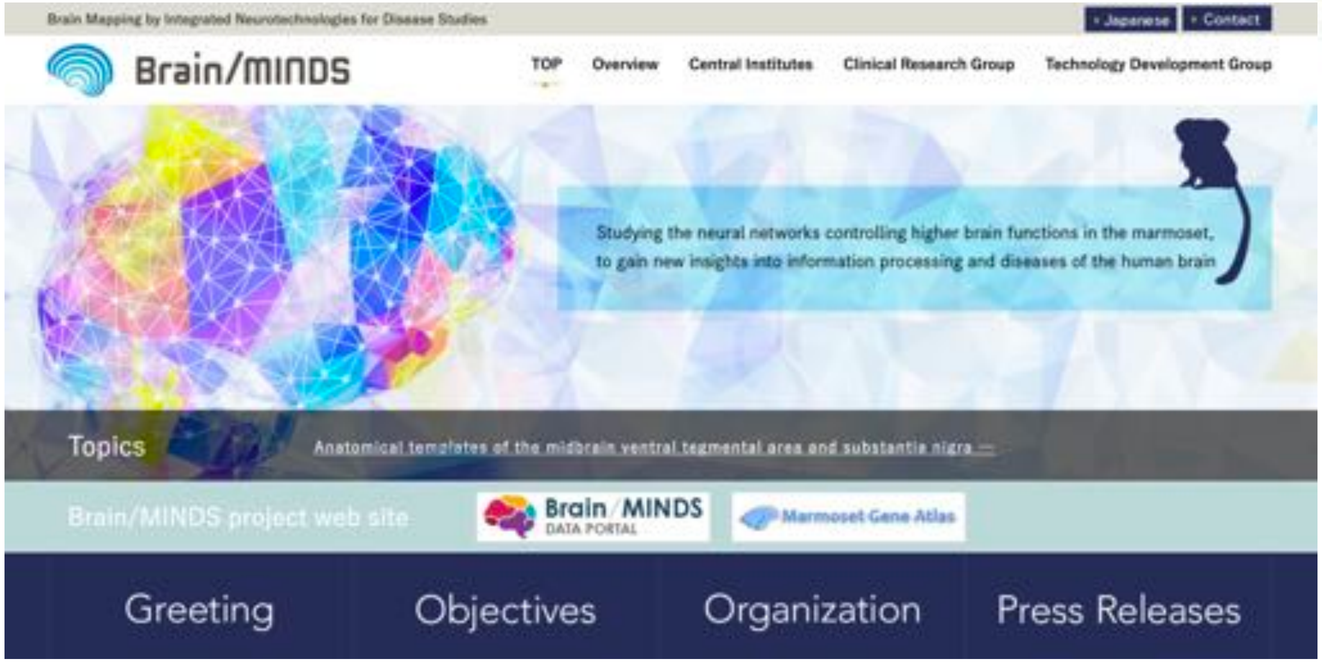


Evolution of brain networks



Van den Heuvel, M.P. et al., (2016) TICS

Brain/MIND project (2014-) in Japan



Van den Heuvel, M.P. et al., (2016) TICS