Seeding Connectivity
-
Cortical Parcellations

MeCA
Methods and Computational Anatomy Research Group
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Connectivity inference

- Connectivity inference: the brain is modelled as a complex network of interacting regions.

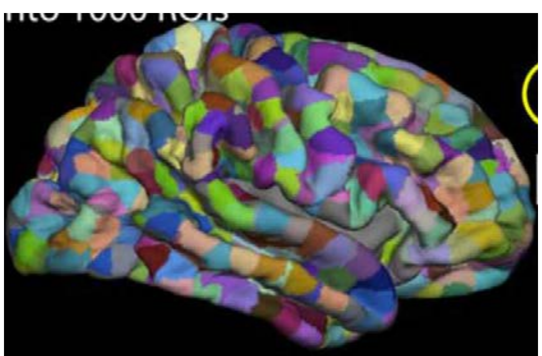
- Interactions can be defined
  - Functionnally: statistical dependency of functional activity
  - Structurally:
    - physical connection (white matter fibers)
    - Statistical dependency of a structural parameter.

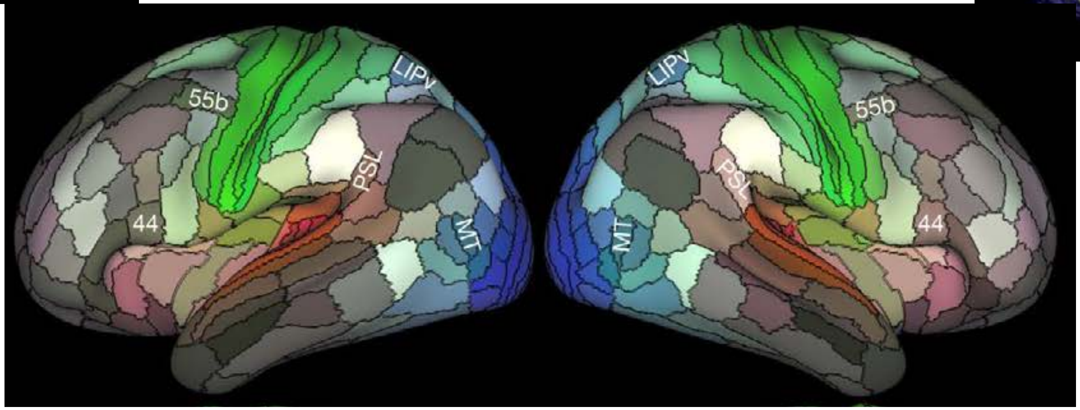
- These interactions are estimated between regions / nodes of a network.

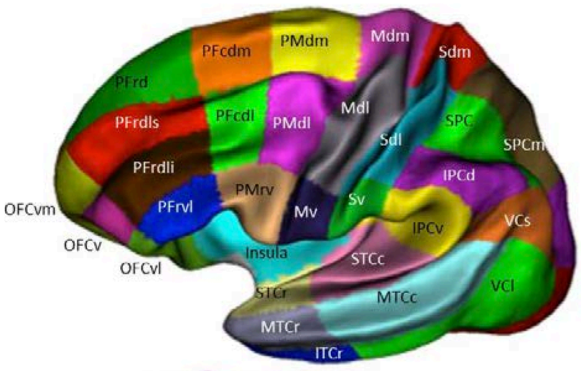
- **How to define these regions ?**

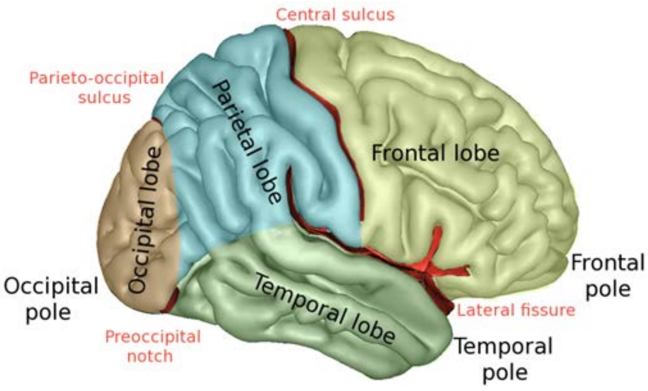
- Parcellating the cortex/brain is dividing it into macroscopic regions that, in the context of connectivity inference, will be potential nodes of brain networks.

Connectivity inference









Cortical parcellations

Parcellation-related issues, in the context of connectivity inference:

Size / Number

- Number: what is the appropriate number of regions: from 10 to >100000 ?
- Size variations: is it OK to have both very small and very large regions in the same parcellation ?

- Integrity: should we define regions with respect to their functional role or connectivity ?
- Fit with local macro-anatomy: do we want regions that follow macro anatomical landmarks (e.g. folds) ?
- Reproducibility: are regions aquivalent across subjects ?

Anatomical / Spatial definition

Overview

Number and size of regions

Spatial definition of regions

Cortical variability and inter-subject correspondences
Functional Homogeneity

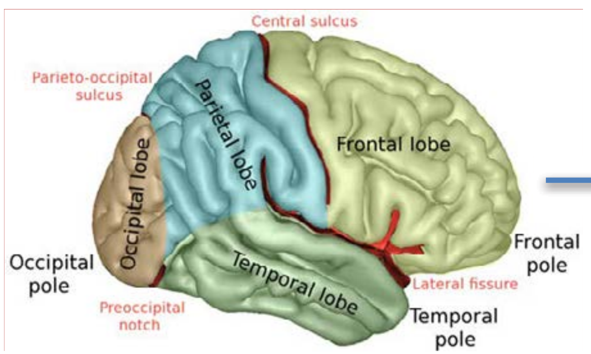
Building parcellations from

Macro-anatomy
Micro-structure
Multi-modal information
Random/high resolution parcellations
Connectivity

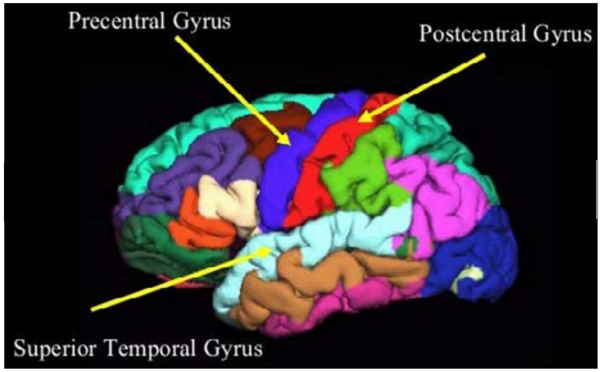
Number and size of regions

Resolution / region size

- What is the optimal size/number of regions ?
- What choices do we have ?

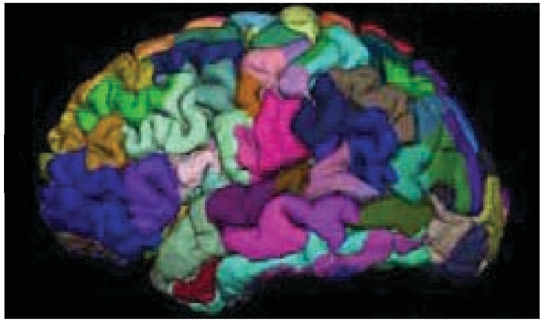


Lobes (n≈10)

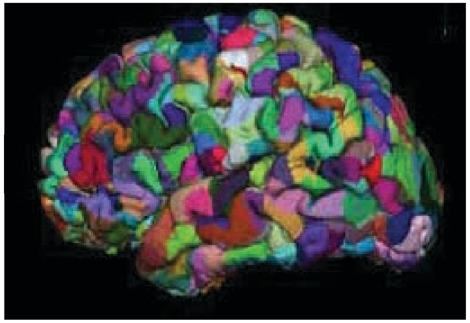


Gyri (n≈70)

Finer (n≈150)



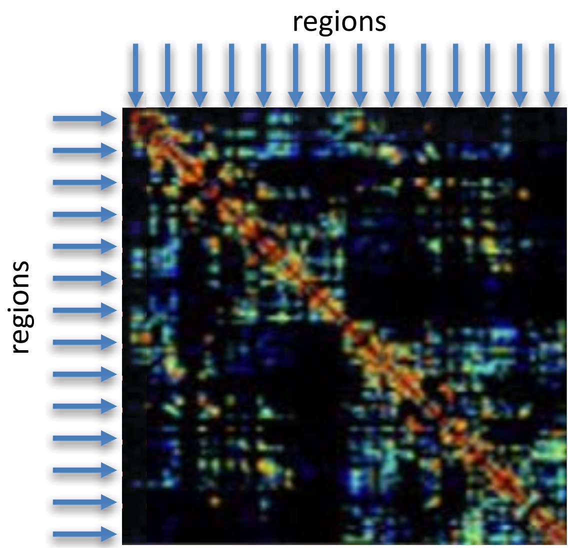
Even finer (n≈200)



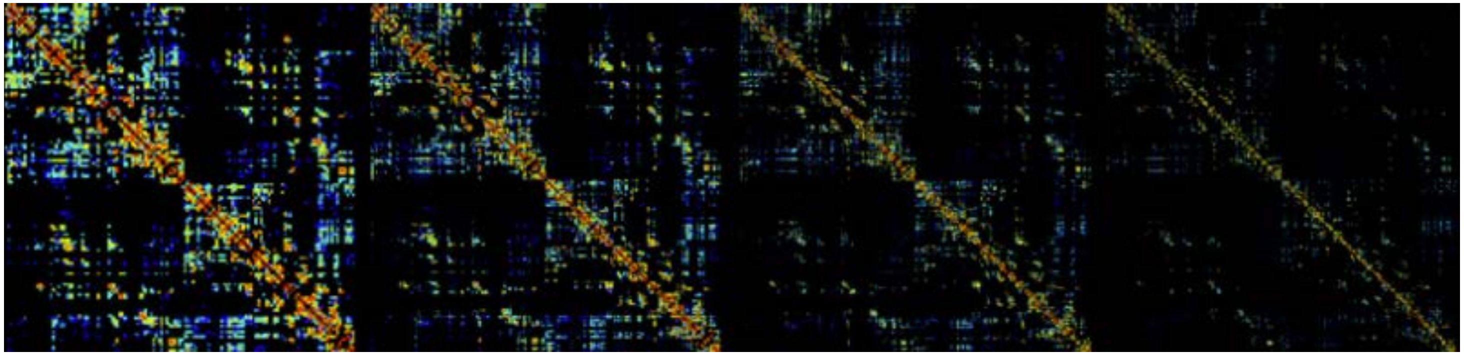
Very fine (n≈1000)

Voxels
n≈100000

Representation



n=70 ⇒ 4900 values (> 4kB)
n=100000 ⇒ 10^{10} values (> 9GB)



n=133 n=241 n=483 n=998

From (Cammoun et al., J. neuroscience methods, 2012)

Anatomical connectivity

What is the influence of the number of regions on the structural connectivity infered from diffusion imaging ?

NeuroImage 80 (2013) 397–404

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The parcellation-based connectome: Limitations and extensions

CrossMark

Marcel A. de Reus *, Martijn P. van den Heuvel

Department of Psychiatry, Rudolf Magnus Institute, University Medical Center Utrecht, 3584 CX Utrecht, The Netherlands

NeuroImage 54 (2011) 1262–1279

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Conserved and variable architecture of human white matter connectivity

Danielle S. Bassett [a,*], Jesse A. Brown [b,c], Vibhas Deshpande [d], Jean M. Carlson [a], Scott T. Grafton [e]

Journal of Neuroscience Methods 203 (2012) 386–397

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Mapping the human connectome at multiple scales with diffusion spectrum MRI

Leila Cammoun [a,*], Xavier Gigandet [a], Djalel Meskaldji [a], Jean Philippe Thiran [a],
Olaf Sporns [b], Kim Q. Do [c], Philippe Maeder [d], Reto Meuli [d], Patric Hagmann [a,d]

Functional connectivity

What is the influence of the number of regions on the functional connectivity infered from fMRI ?

frontiers in
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ORIGINAL RESEARCH ARTICLE
published: 17 June 2010
doi: 10.3389/fnsys.2010.00022

Network scaling effects in graph analytic studies of human resting-state fMRI data

Alex Fornito[1,2], Andrew Zalesky[2] and Edward T. Bullmore[1,3]*

frontiers in
COMPUTATIONAL NEUROSCIENCE
REVIEW ARTICLE
published: 22 November 2013
doi: 10.3389/fncom.2013.00169

Defining nodes in complex brain networks

Matthew L. Stanley, Malaak N. Moussa, Brielle M. Paolini, Robert G. Lyday, Jonathan H. Burdette and Paul J. Laurienti*

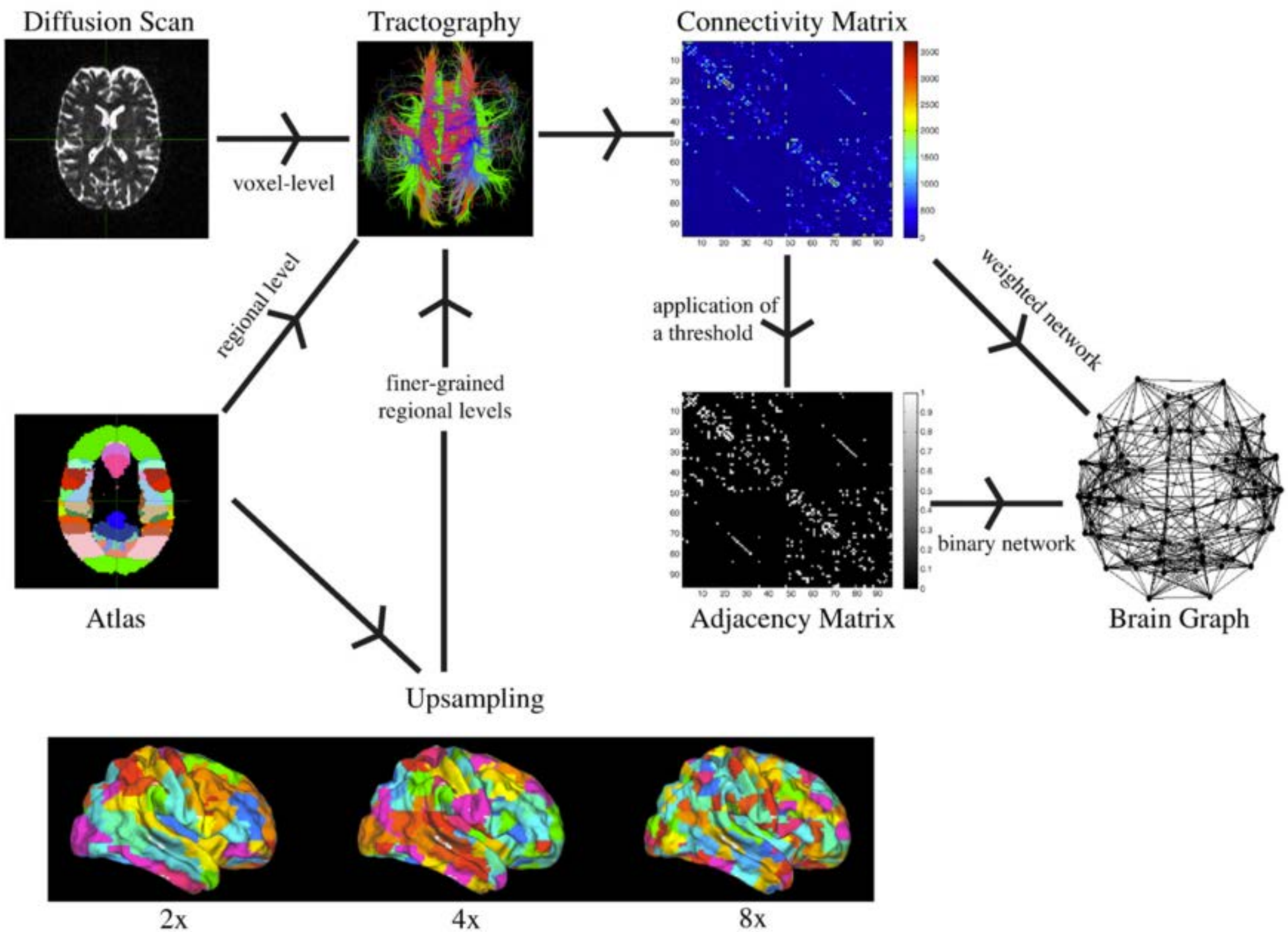
♦ Human Brain Mapping 30:1511–1523 (2009) ♦

Parcellation-Dependent Small-World Brain Functional Networks: A Resting-State fMRI Study

Jinhui Wang,[1†] Liang Wang,[1,2†] Yufeng Zang,[1] Hong Yang,[3] Hehan Tang,[3] Qiyong Gong,[3] Zhang Chen,[4] Chaozhe Zhu,[1*] and Yong He[1,4*]

Number of regions and connectivity

(Bassett et al., 2011)



Measurements

How to measure the influence of the number of regions ?

Graph metrics:

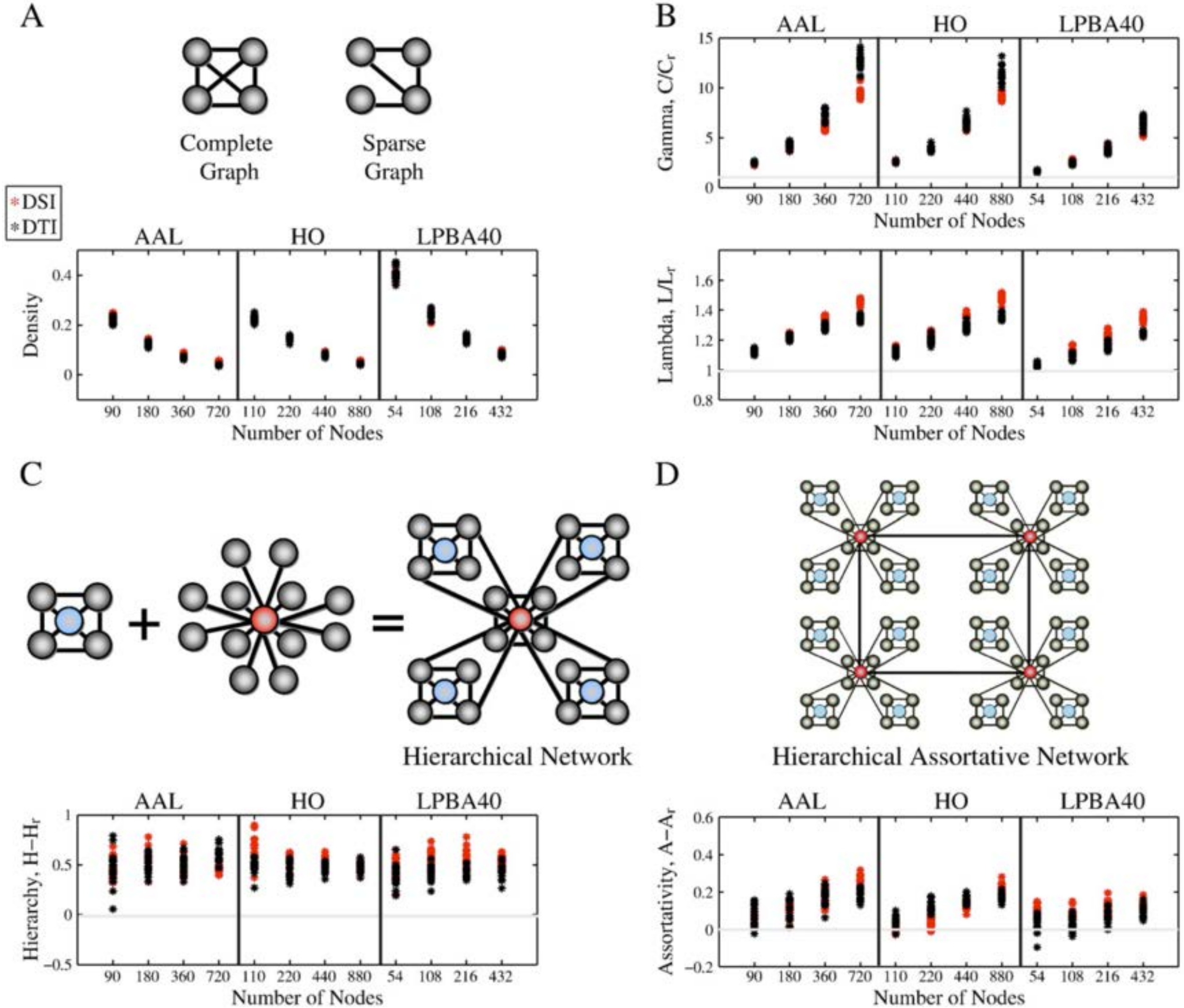
- Basic connectivity properties: density (numb. of edges/max number of edges), average weight (average weights of edges), tract length, etc…
- Graph properties (organisation, topology): small-worldness, hierarchy, assortativity, ...

Variability:

- Within-subject
- Across subjects
- Measured by correlating connectivity matrices

Metrics

(Bassett et al., 2011)



Number of regions - conclusions

- The nature/organisational principles of the infered network is fairly constant with the number of regions (low density, sparse, small-world, hierarchical, assortative)
- But: the number of nodes has a strong impact on graph metric values
- At equivalent number of regions, metric variations are small (<3%) across atlases (Humphries et al., 2006).

⇒ the number of regions has a stronger impact than the regions boundaries
⇒ when comparing studies, or populations, it is important to use equivalent parcellations.

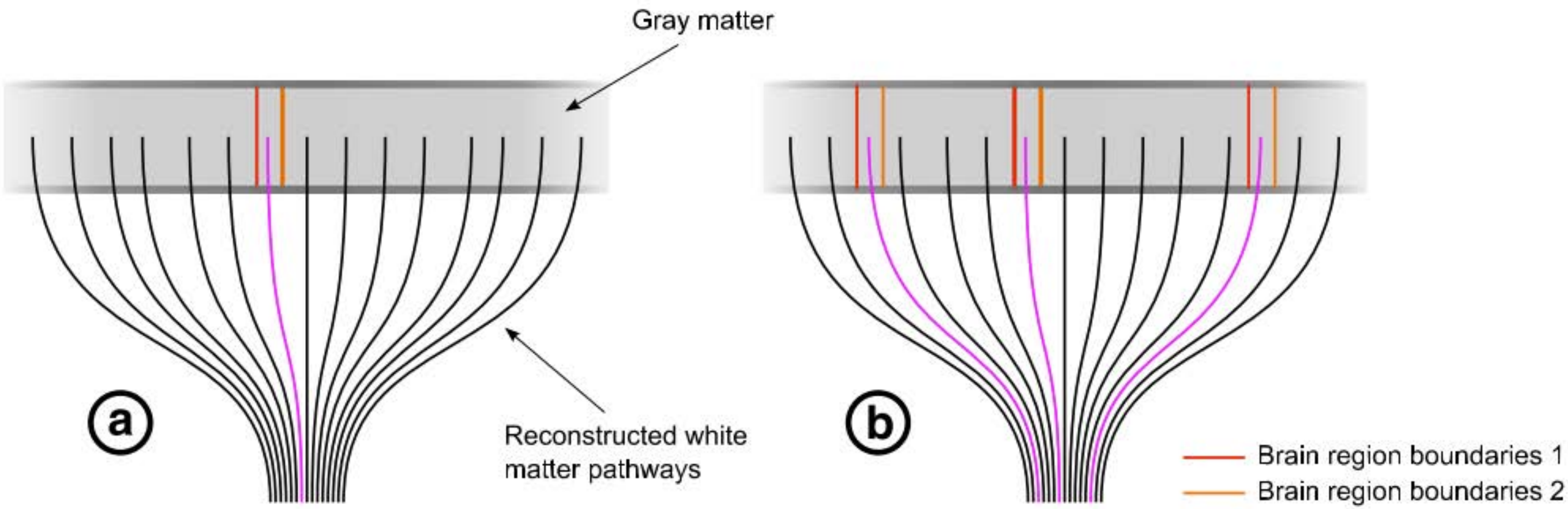
- Individual differences in functional connectivity is better preserved for n>200 and particularly reproducible for n≈1000 (Fornito et al., 2010).

- But: when increasing region number and decreasing region size, the impact of noise is larger.
- Increasing the number of regions ⇒ decreasing region size ⇒ challenging inter-subject correspondences

Region boundaries

Increasing the number of regions ⇒ decreasing region size
⇒ challenging inter-subject correspondences

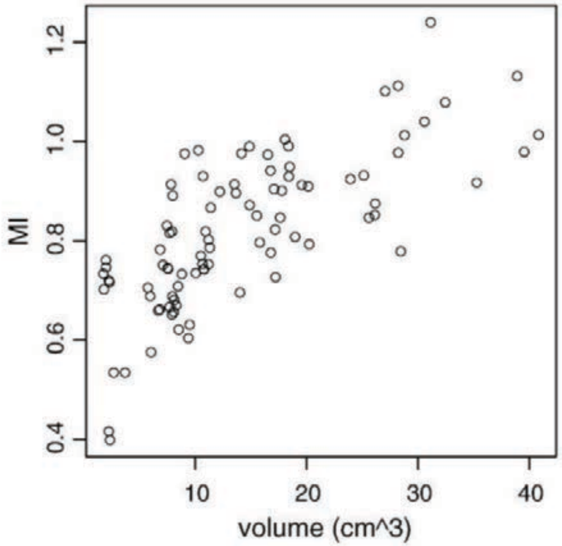
M.A. de Reus, M.P. van den Heuvel / NeuroImage 80 (2013) 397–404



Variable region size

- In functional connectivity, signal is generally averaged between voxels of a same region, and correlations between average signals of different regions are estimated.

- Problems if the region size is spatially variable:
  - SNR of each regional signal is depending on the number of voxels that have been averaged
  - See e.g. (S. Achard et al., In IEEE Workshop on Statistical Signal Processing, 2011.); (Salvador et al., NeuroImage, 2008)



- So it is recommended to have regions that do not vary too much in size.

.... but most atlases do not fulfill this criterion.

- Size heterogeneity could also be a intrinsic biological property (Van Essen et al., 2012),

Practical conclusions

- There is no answer yet to what is the optimal number/size of regions
- Your choice depends on several factors:
  - The software you are using
  - Your research objectives, e.g.:
    - If parcellating a subcortical structure in a few subregions using its connectivity to the cortex (cf. FSL), no need for a lot of cortical regions.
    - Is there a prior about the functional or anatomical units you are interested in, this can be a criterion for chosing a parcellation.
    - When interested in individual variations of functional connectivity (individual vs. Group, correlation between connectivity and behaviour…) use n>200
  - At equivalent number of regions, chose the parcellation that fits best to individual anatomy (ensure a better producibility).

Spatial definition of regions

Spatial definition of regions

Given a number of regions, how to define locations and boundaries of these regions ?

What can we use ?

- Macro-anatomy: sulci, gyri, anatomical localization in a reference atlas....
- Function ?
- Connectivity ?
- Cyto/Myelo-architectony ?

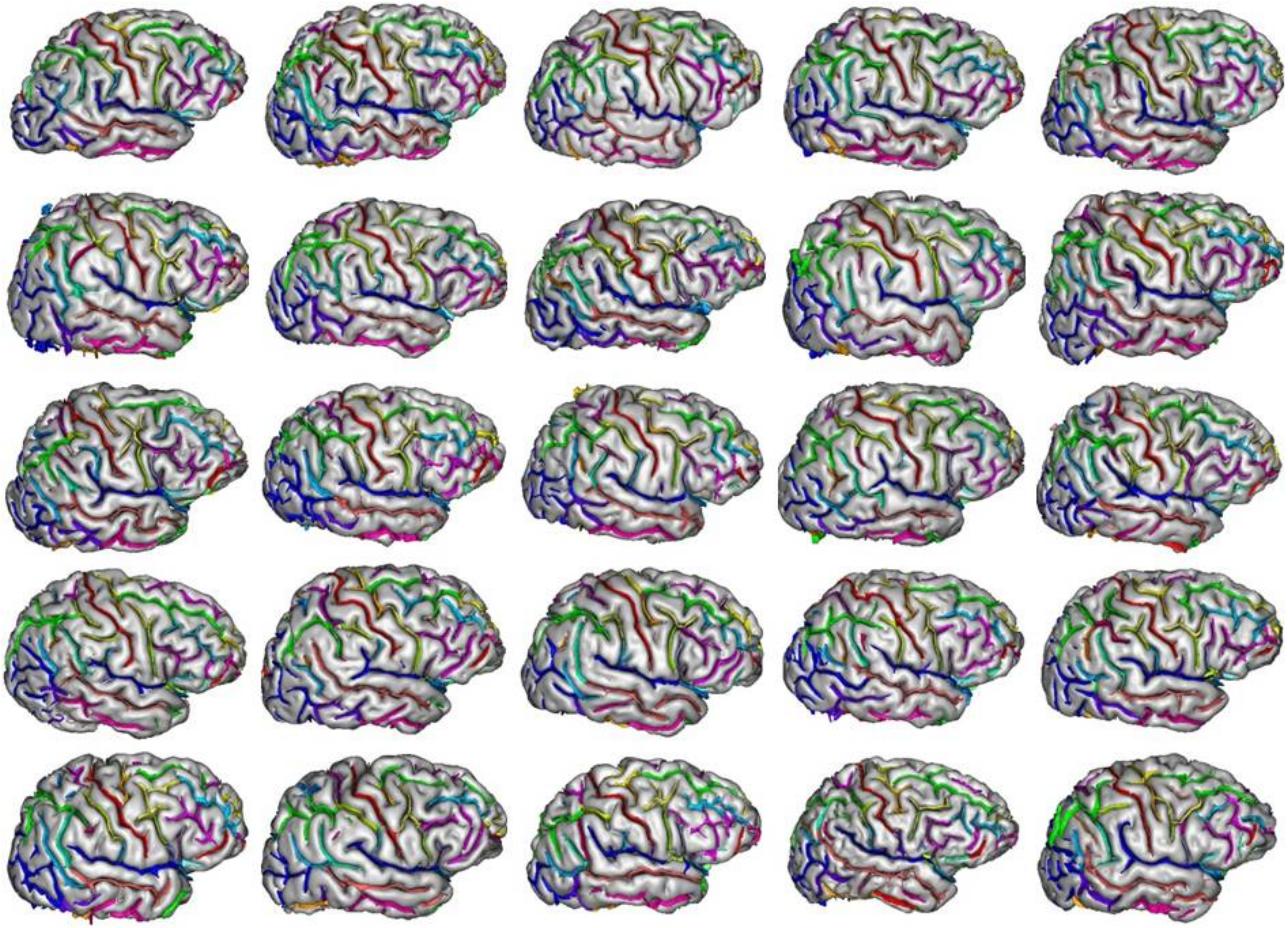
What is important ?

- Good inter-subject correspondences
- Some form of within-region homogeneity

Cortical variability and inter-subject correspondences

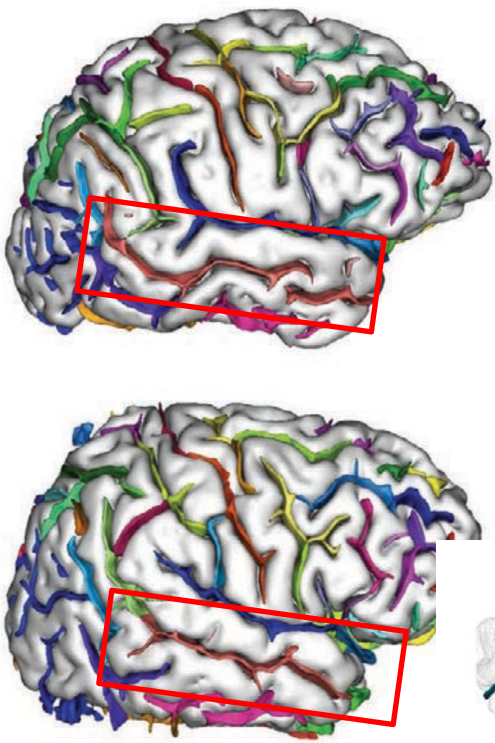
Cortical Variability

…macro-anatomical

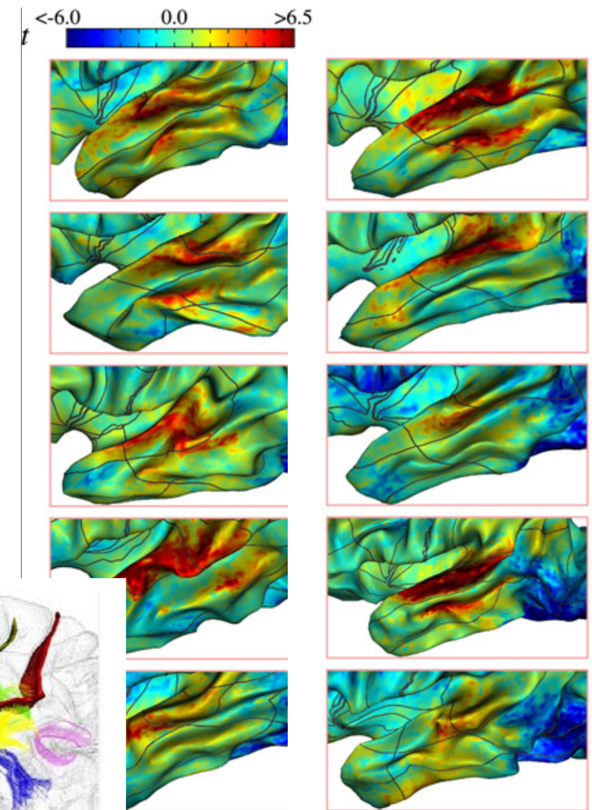


Cortical Variability

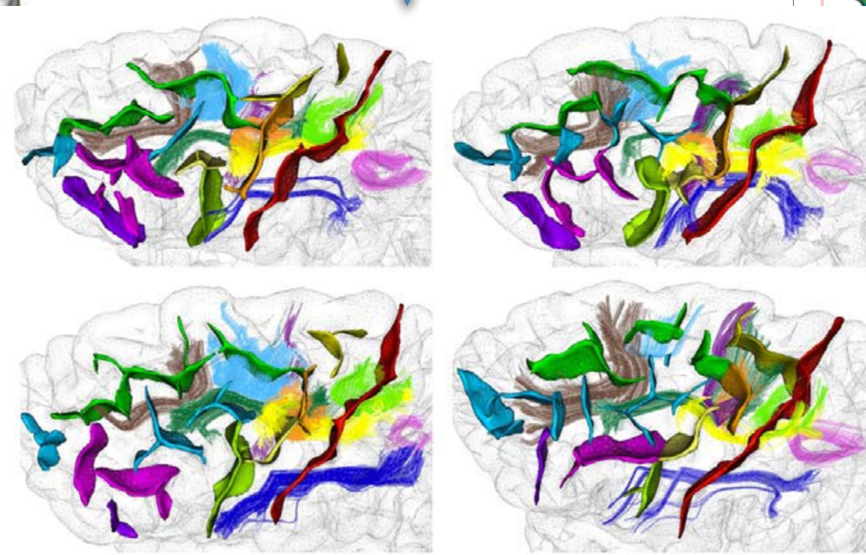
…macro-anatomical



…functional

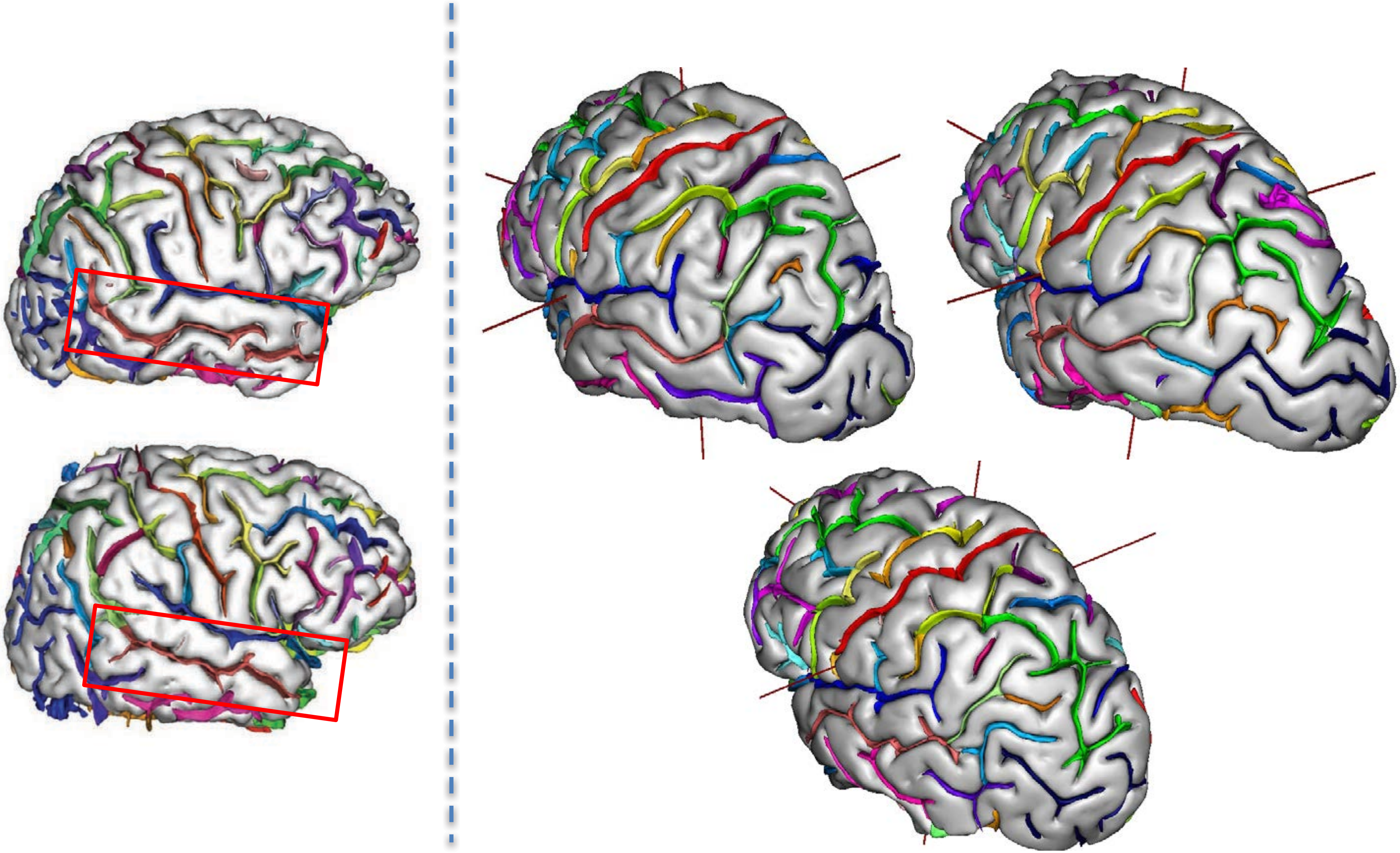


ividual functional activation maps
-to et al., Med Image Analysis, 2012)

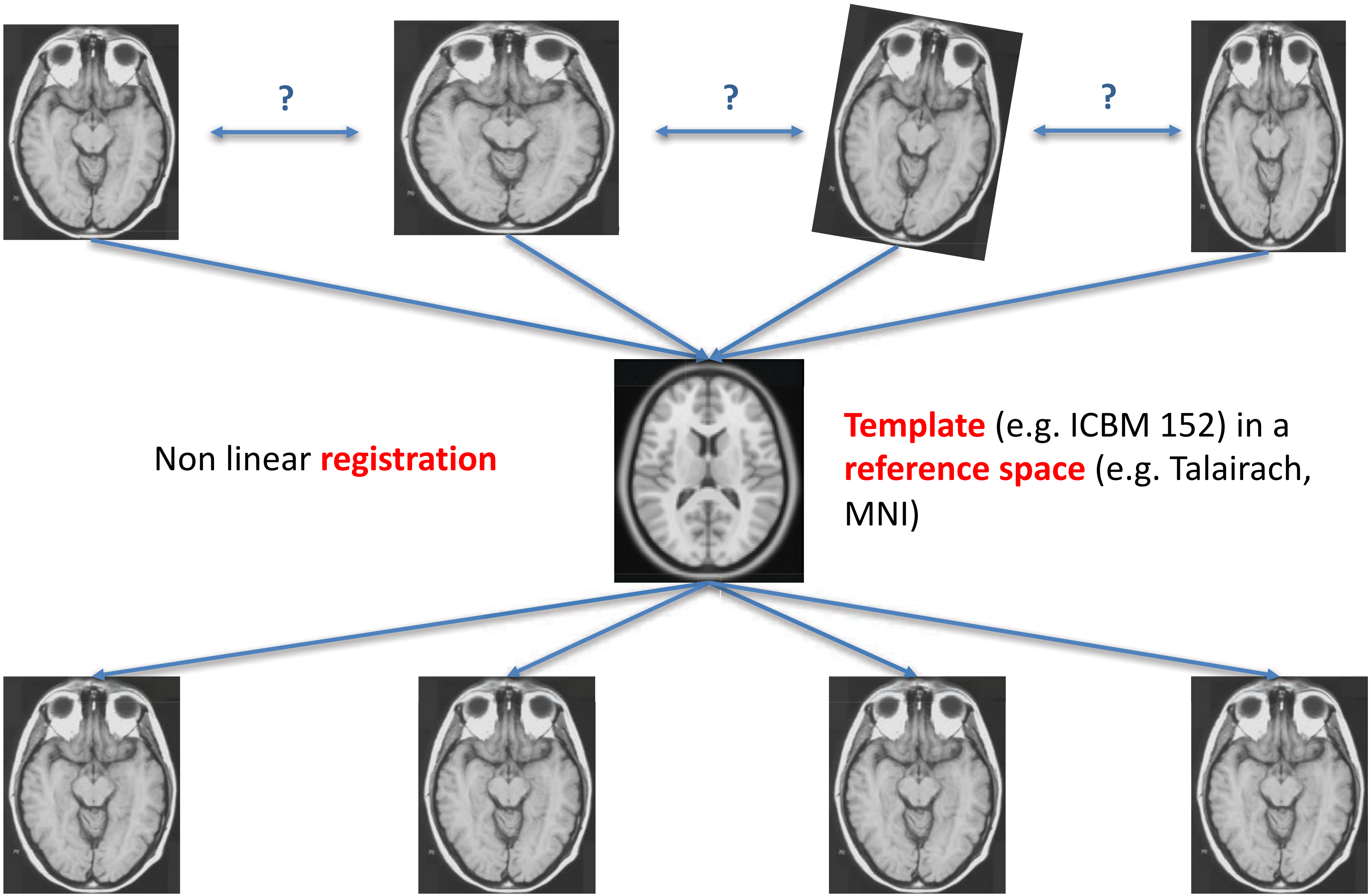


…connectivity

Folding variability



Defining correspondences between subjects

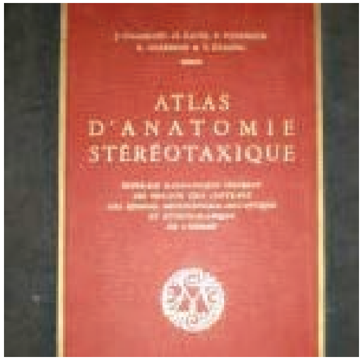


Non linear **registration**

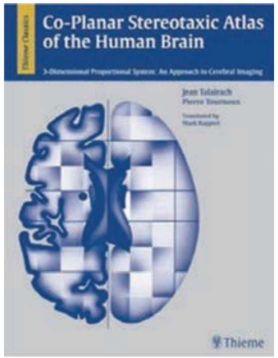
Template (e.g. ICBM 152) in a **reference space** (e.g. Talairach, MNI)

Templates

First template used in neuroimaging: the Talairach atlas



Talairach et al., 1957

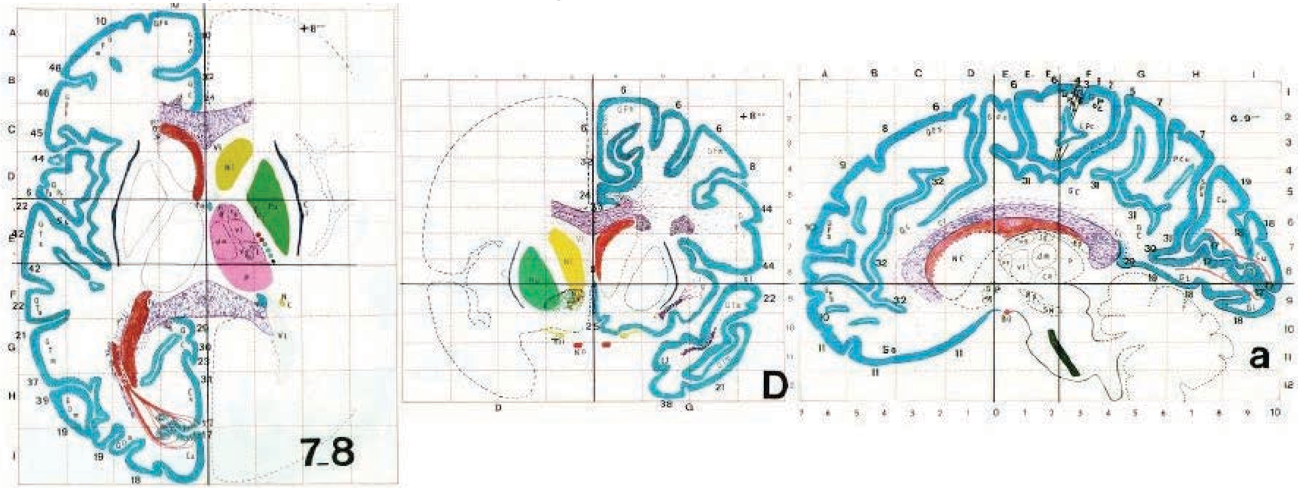


Talairach and Tournoux, 1988

Originally for localization of subcortical structures.

Used for global matching of subjects and perform group statistics, first by P. Fox (Fox et al., 1988).

Associate cordinate system: **Talairach Space**. Still a reference for communicating results.

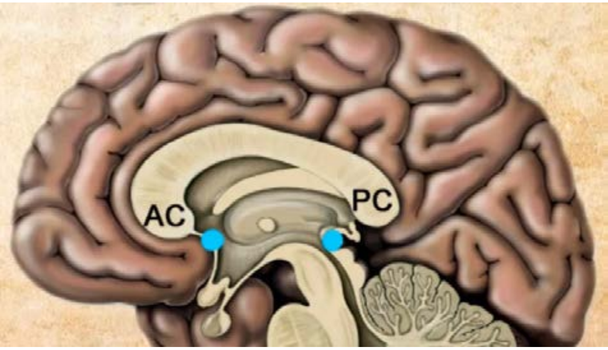


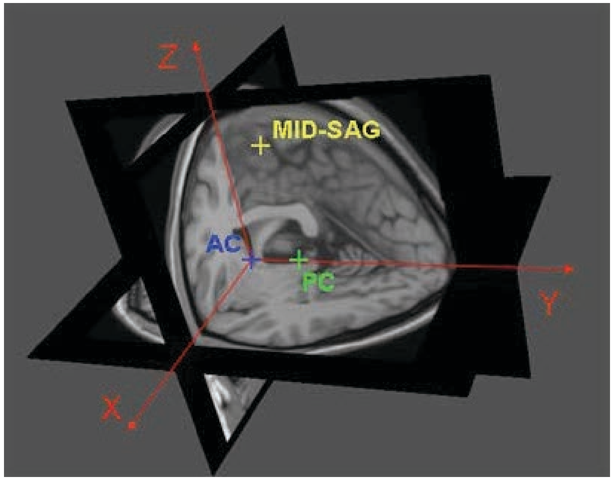
Templates

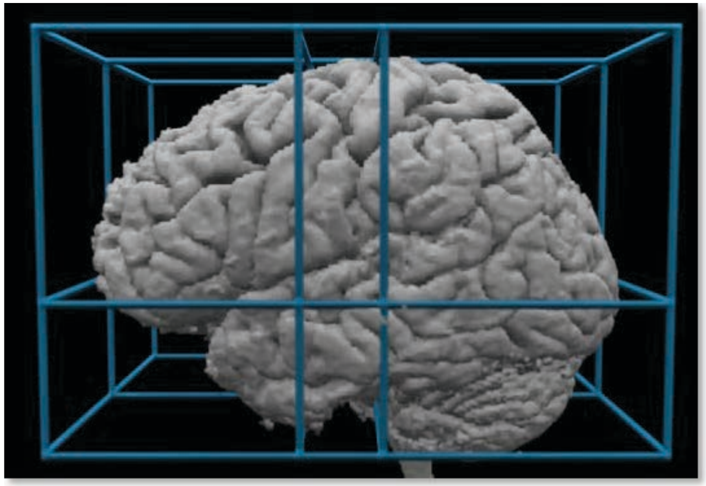
Registration from individual brains to the Talairach atlas is based on two landmarks:

- The intersection of the inter-hemispheric plane and the anterior commissure (AC)
- The intersection of the inter-hemispheric plane and the posterior commissure (PC)

, and the bounding box of the brain.



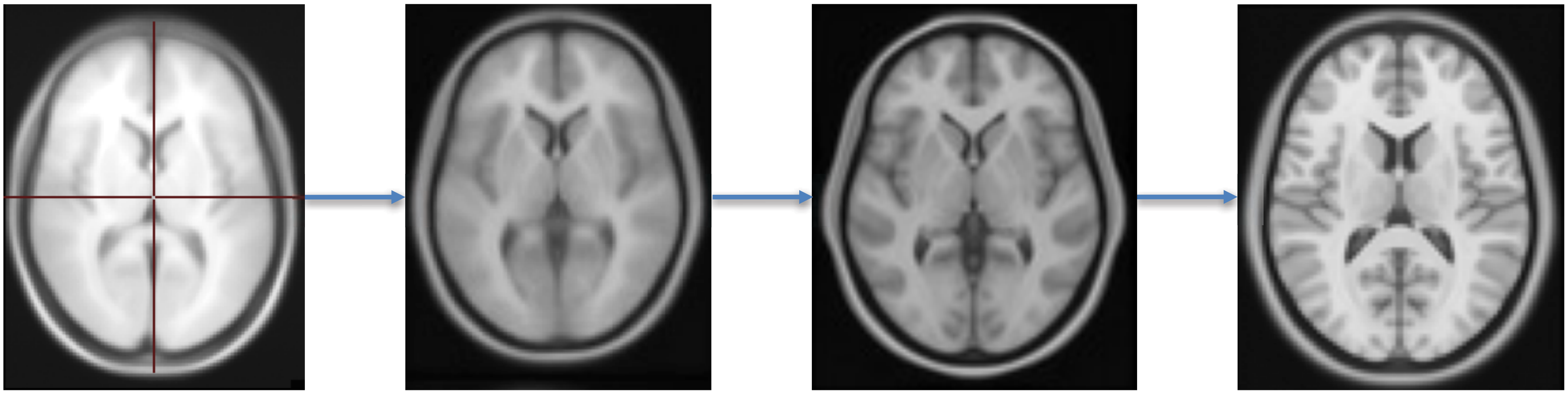




<u>Limitations</u>:

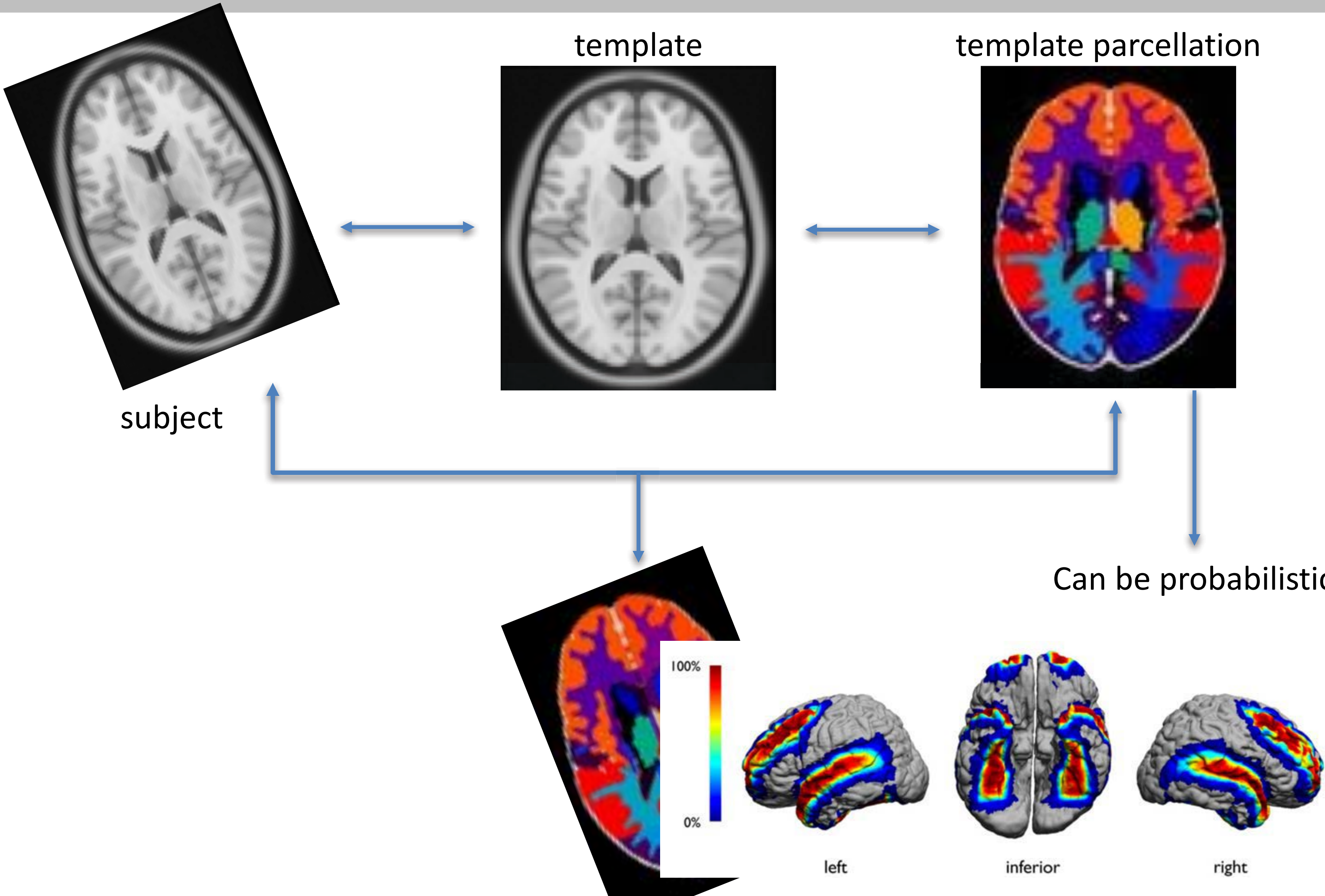
- **Build from one single subject** (post mortem brain, 60 y.o. women) -> not representative
- Very imprecise for cortical areas.

Modern templates / referentials

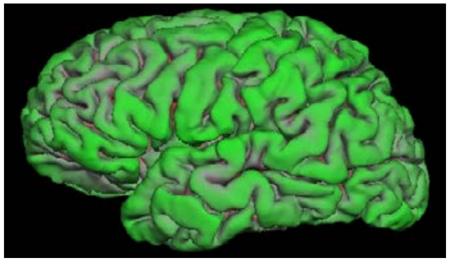


MNI305	ICBM152 lin	ICBM152 non lin	ICBM152 non lin 2009
Averaging (305 subjects) New referential (MNI)	New registration (affine)	New registration (non linear)	Iterative averaging

Parcellation

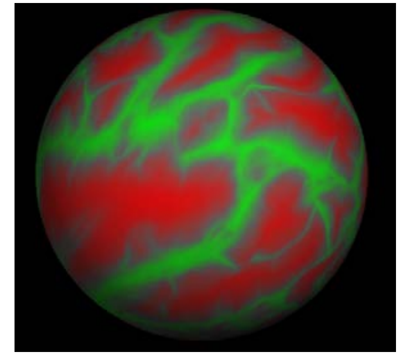


Surface-based strategy

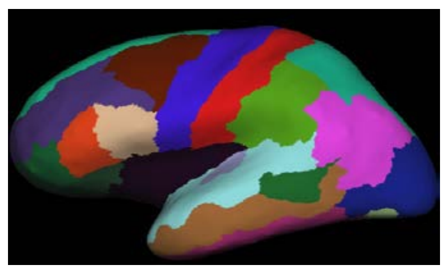


Cortical surface

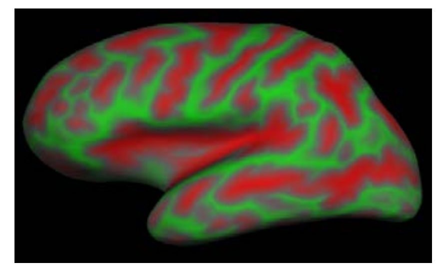
Mapping to a sphere



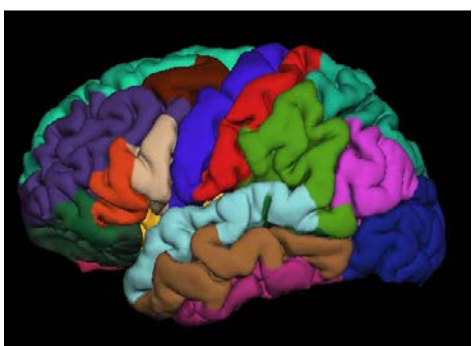
Registration to an average model



Parcellation model



Correspondance with an average surface



(FreeSurfer, https://surfer.nmr.mgh.harvard.edu/)

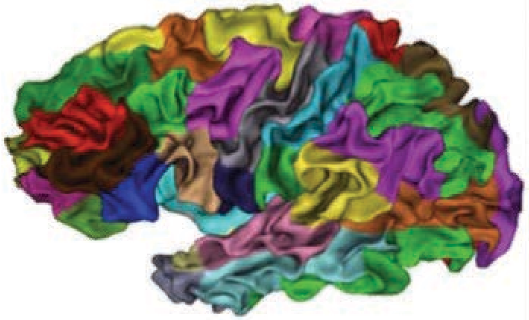
Volume or surface ?

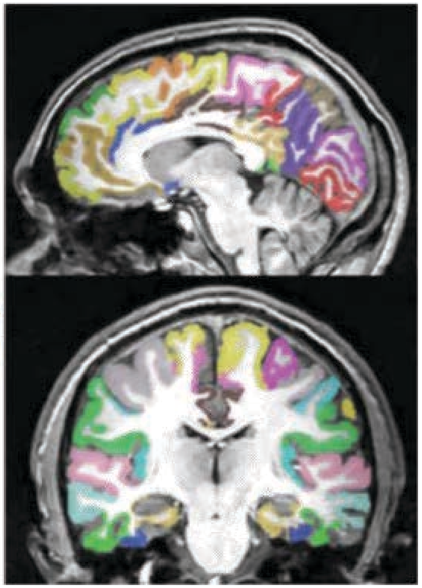
- Volume-based registration **cannot** align perfectly cortical structures across individuals.

- Surface-based does a better job by nature (see for instance: Van Essen et al., *Functional and structural mapping of human cerebral cortex: Solutions are in the surfaces*, PNAS, 1998)

- But:
  - Surface-based analysis require a good segmentation/extraction of the cortical surface
  - You might (often) want to parcellate the cortical volume anyway
  - Volume-based methods generally provide sub-cortical parcellation as well

- Rem: some software packages (FreeSurfer, BrainVisa) offer the possibility to propagate a cortical surface parcellation to the gray matter volume.

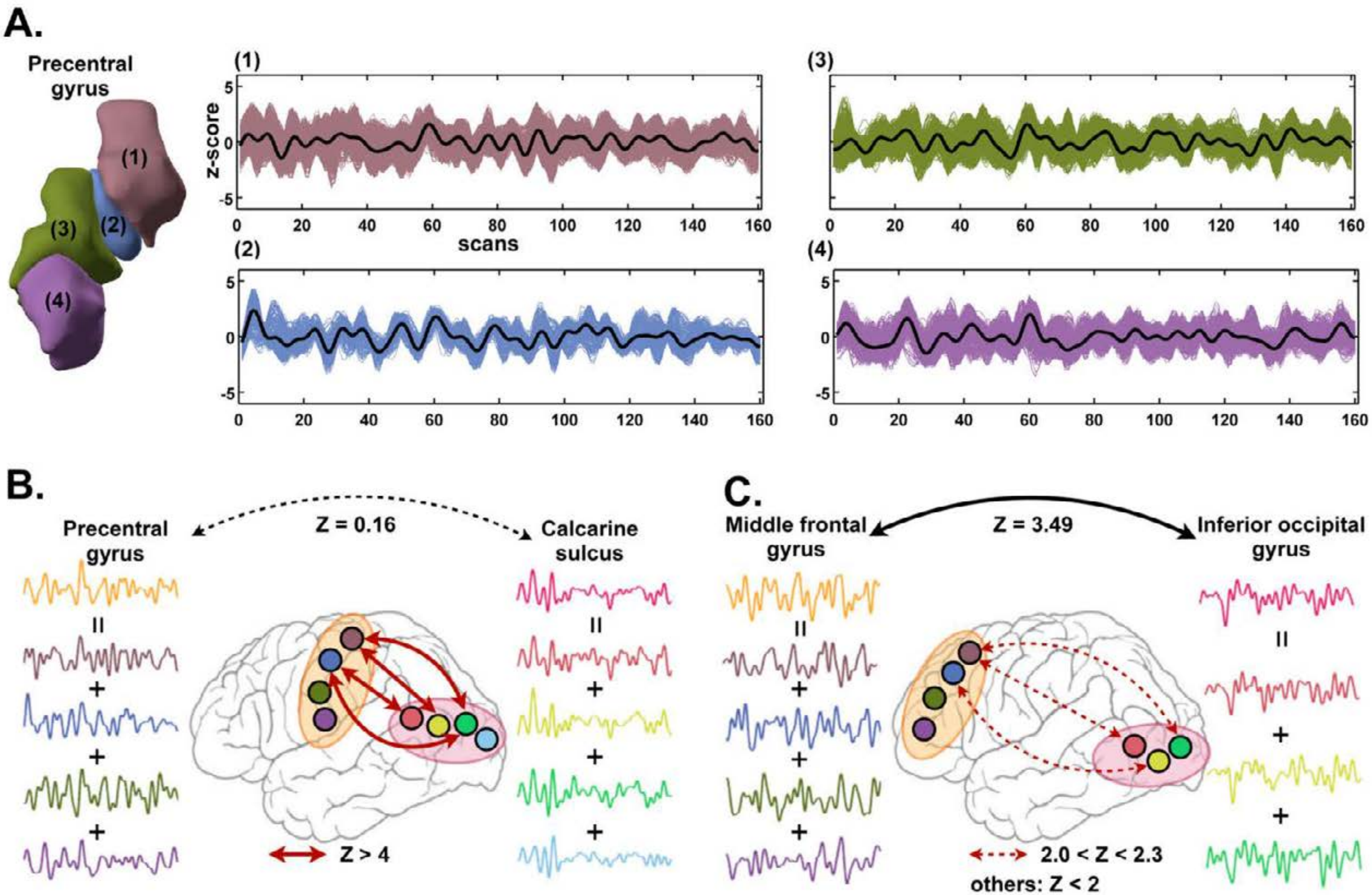




Functional homogeneity

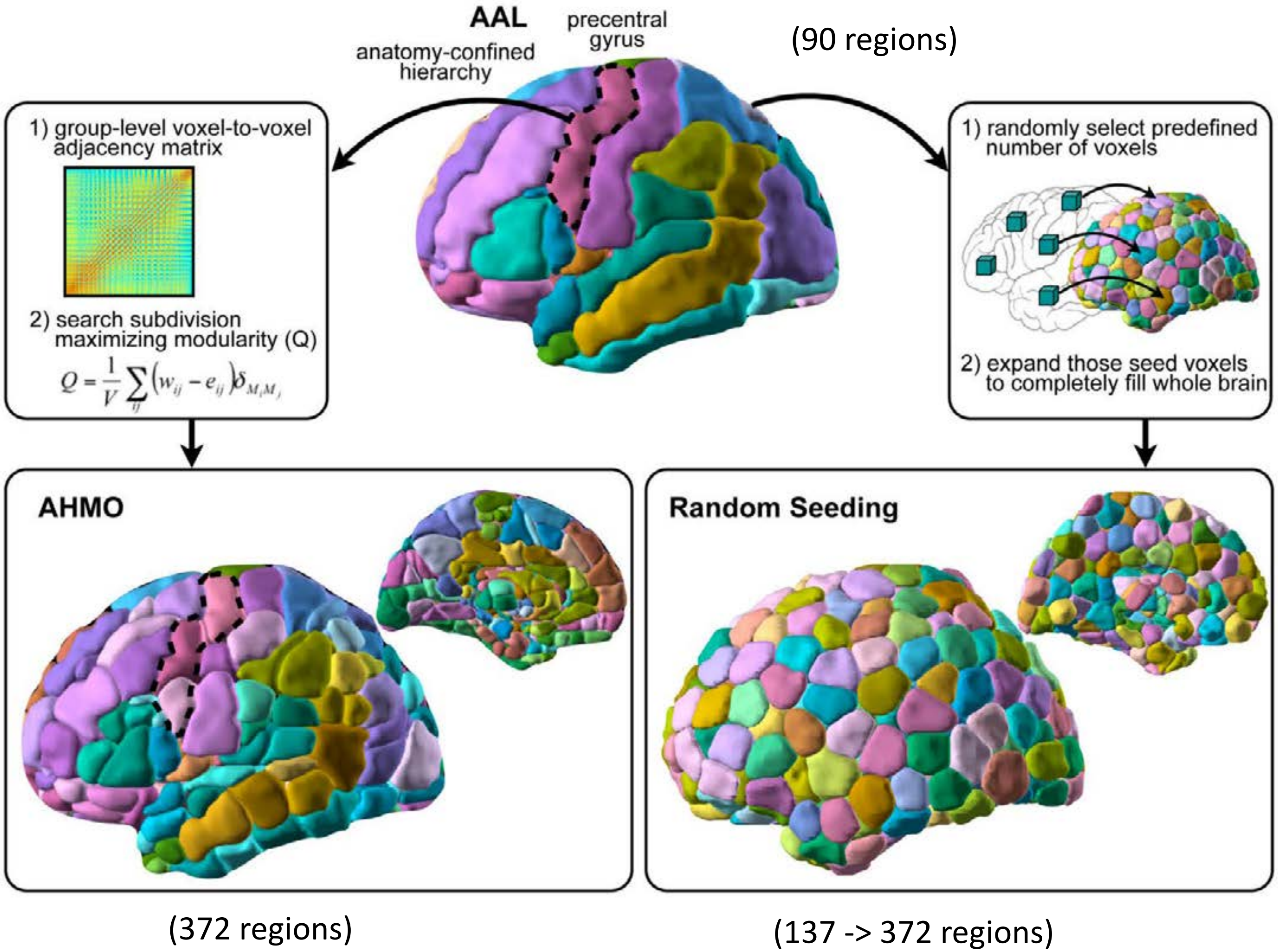
What about functional homogeneity ?

What if a region contain several ‘functional units’, with different activity time course ?



From (Park et al., *PLoS ONE*, *8*(9), 2013.)

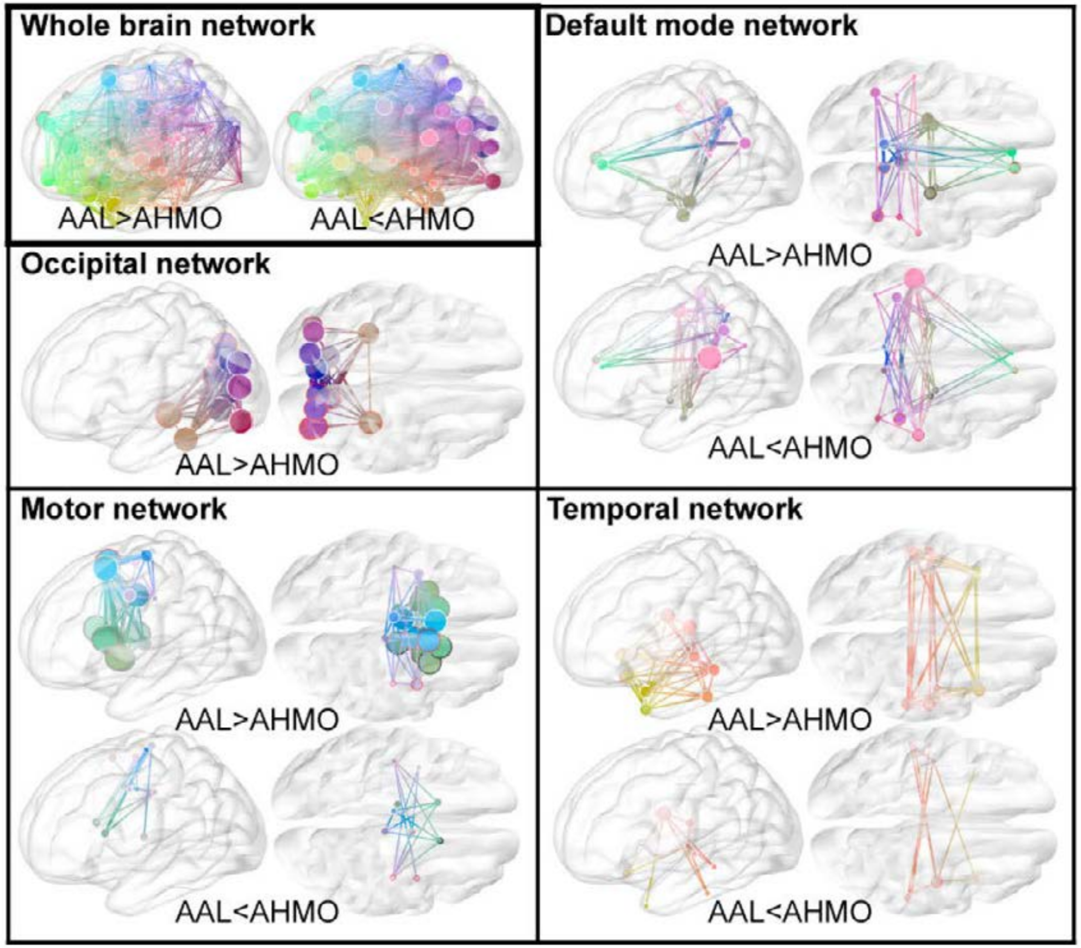
Functional homogeneity



(Park et al., *PLoS ONE*, *8*(9), 2013.)

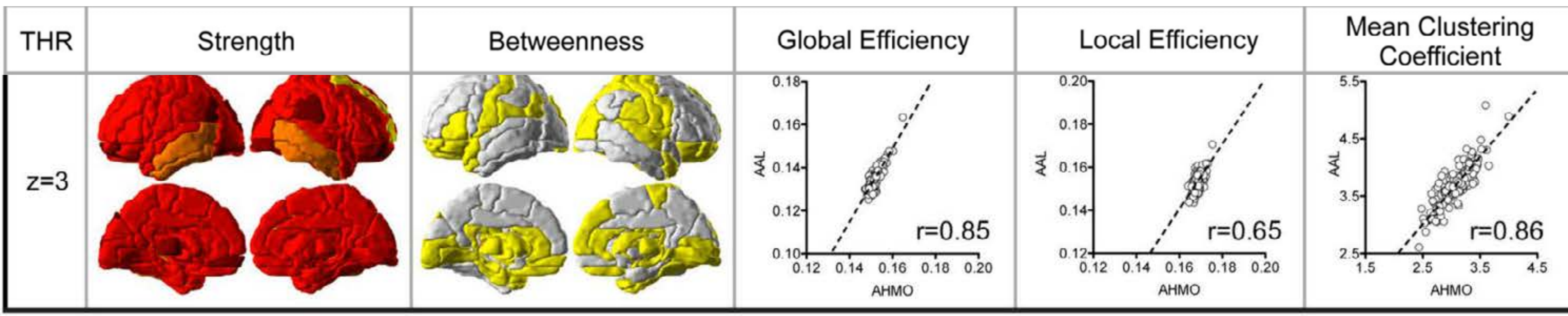
Functional homogeneity

- inhomogeneous regions as nodes leads to changes in the functional connectivity and global network properties



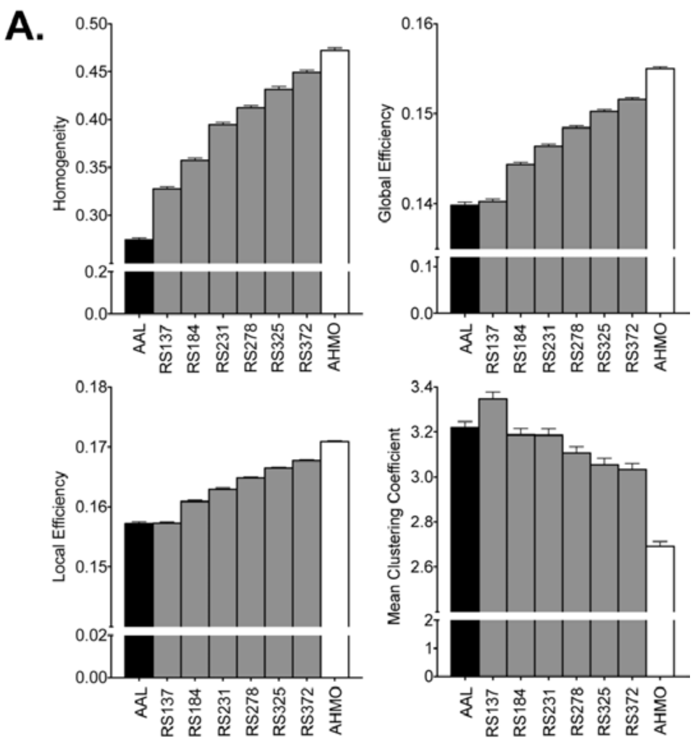
Functional homogeneity

- inhomogeneous regions as nodes leads to changes in the functional connectivity and global network properties
- Some graph-theoretical measures are affected by inhomogeneities, but strong correlations across atlases for a lot of them.



Functional homogeneity

- inhomogeneous regions as nodes leads to changes in the functional connectivity and global network properties
- Some graph-theoretical measures are affected by inhomogeneities, but strong correlations across atlases for a lot of them.
- Functional homogeneity increases with the number of nodes, but anatomical borders are important as well.



Functional homogeneity

- inhomogeneous regions as nodes leads to changes in the functional connectivity and global network properties
- Some graph-theoretical measures are affected by inhomogeneities, but strong correlations across atlases for a lot of them.
- Functional homogeneity increases with the number of nodes, but anatomical borders are important as well.

$\Rightarrow$ the use of low-resolution atlases is OK for most network characteristics, but the same atlas must be used for comparisons. Small nodes increase functional homogeneity, anatomical border helps.

Building parcellations from macro-anatomy

Building parcellations from macro-anatomy

- Parcellating the cortex from macro-anatomical information means defining regions on the basis of the observable cortical macro-anatomy.
- Most of the time, such macro-anatomy is characterized by its folding patterns (sulci, gyri).
- It often implicitely assumes a relationship between macro-anatomy and functional ‘units’ (or connectivity units), e.g.:
    - cortical folds are meaningful separators between cortical areas.
    - gyri are functionnally relevant (if not homogeneous) units.

AAL – automated anatomical labelling

NeuroImage 15, 273–289 (2002)
doi:10.1006/nimg.2001.0978, available online at http://www.idealibrary.com on IDEAL®

TECHNICAL NOTE

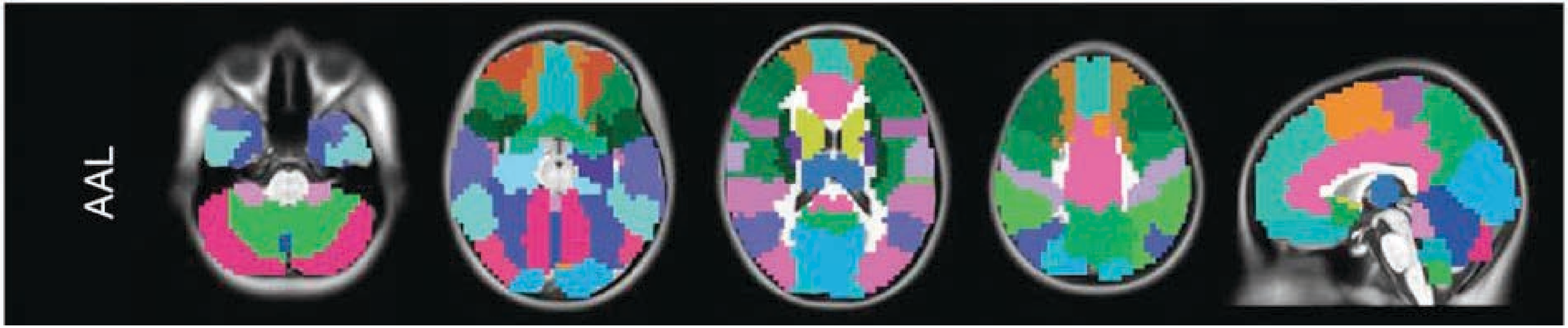
Automated Anatomical Labeling of Activations in SPM Using a Macroscopic Anatomical Parcellation of the MNI MRI Single-Subject Brain

N. Tzourio-Mazoyer, B. Landeau,* D. Papathanassiou, F. Crivello, O. Etard, N. Delcroix, B. Mazoyer,† and M. Joliot[1]

The most used atlas for functional resting state connectivity

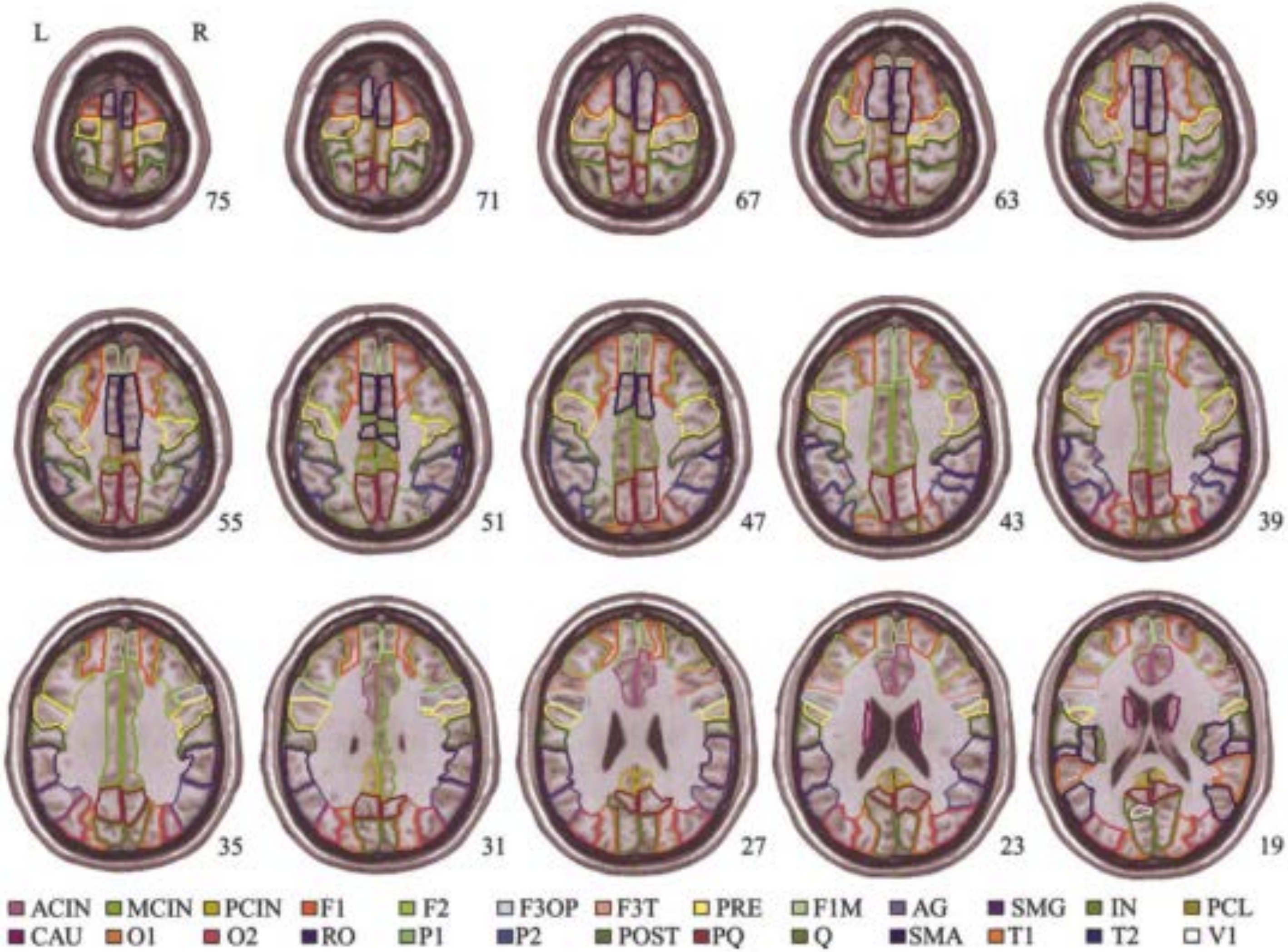
AAL

AAL: automatic anatomical labelling
(Tzourio-Mazoyer et al., 2002)



- Made from a single subject in the MNI space.
- 45 regions per hemispheres (cortical and subcortical, excluding cerebellum)
  $\Rightarrow$ **90 regions overall**
- Made from anatomical landmarks (sulci and gyri)
- Originally developed to anatomically label functional results
- Not very precise in cortical regions
- Very easy to use with the SPM package (http://www.fil.ion.ucl.ac.uk/spm/)

AAL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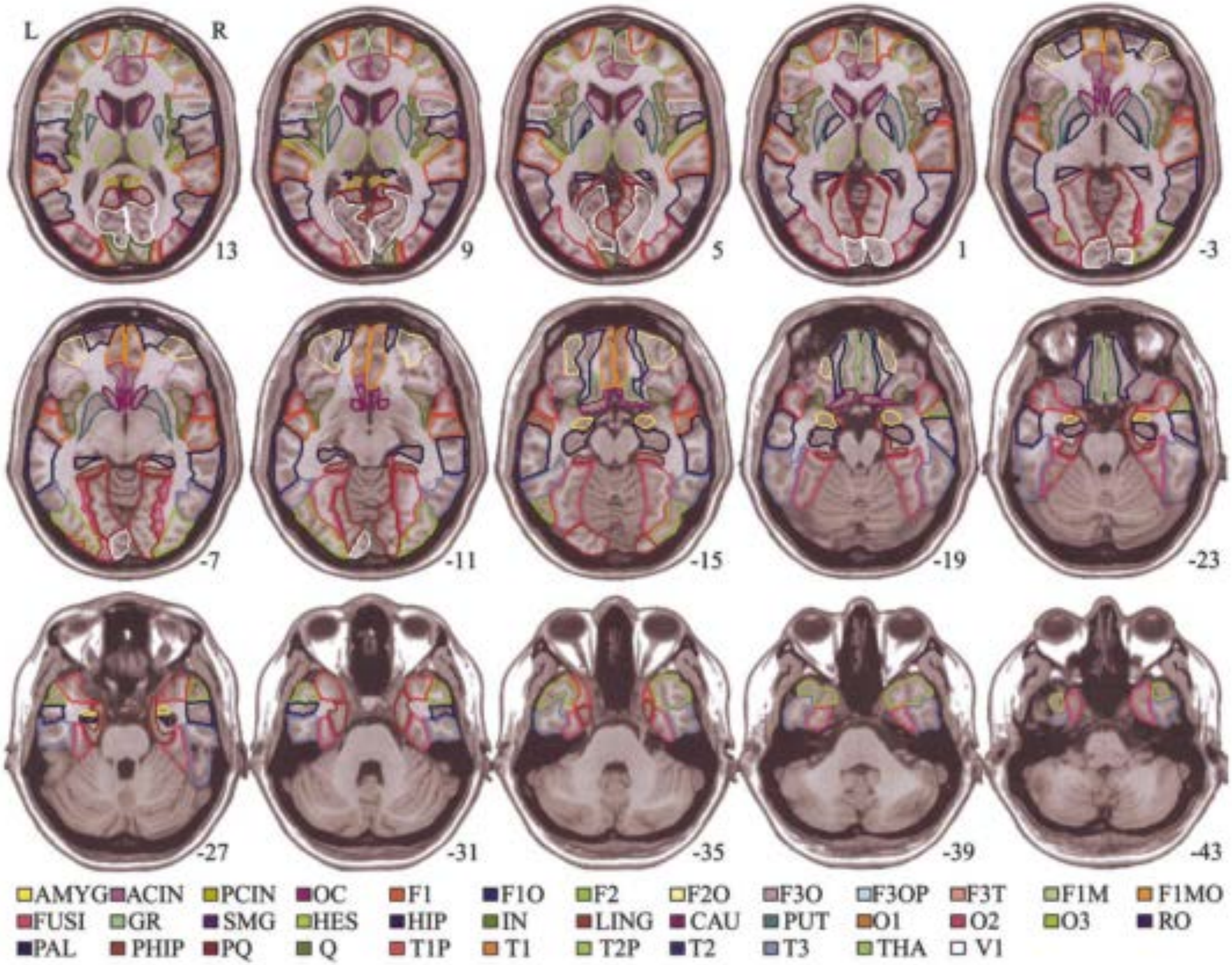
T2
V1

AAL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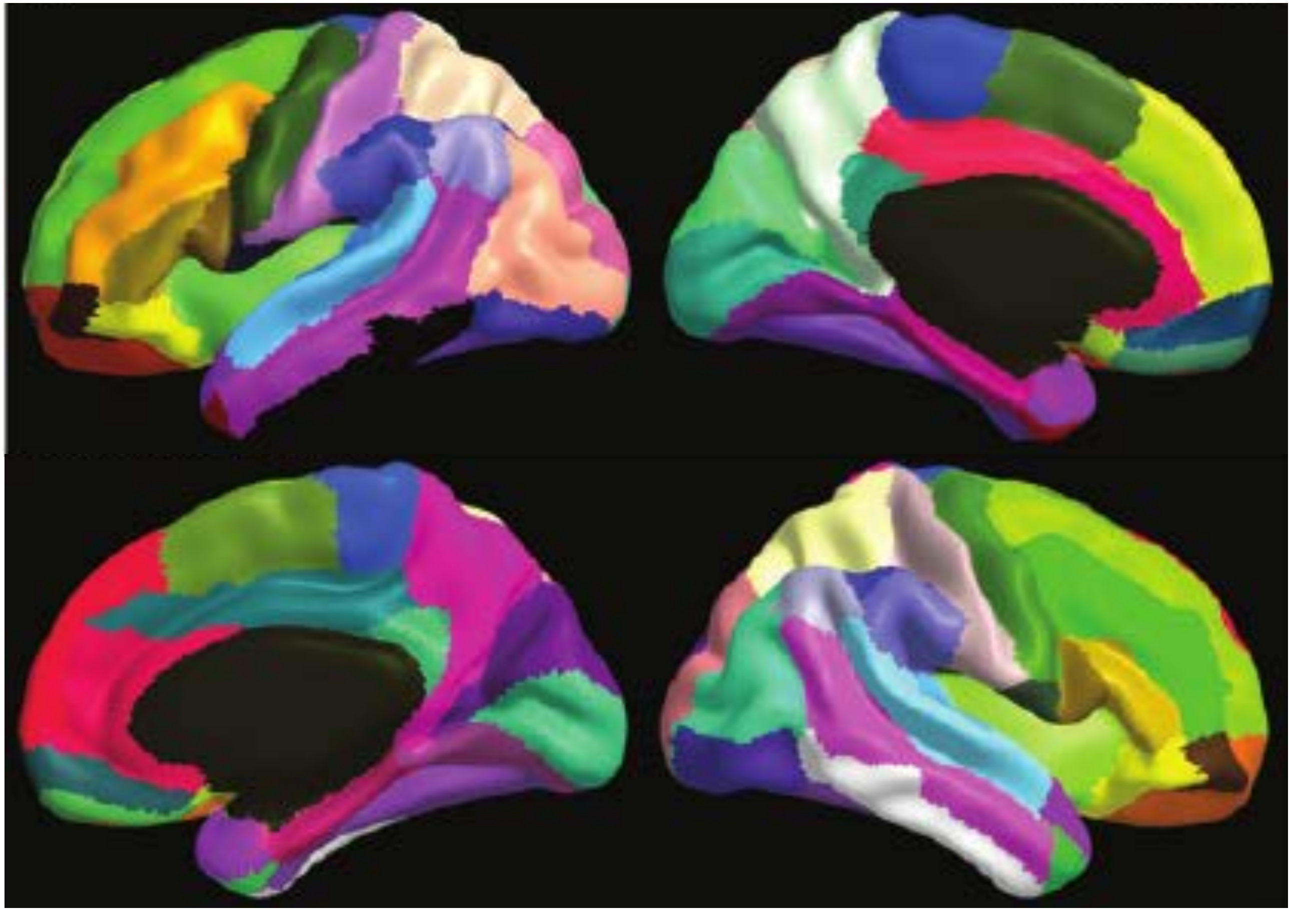
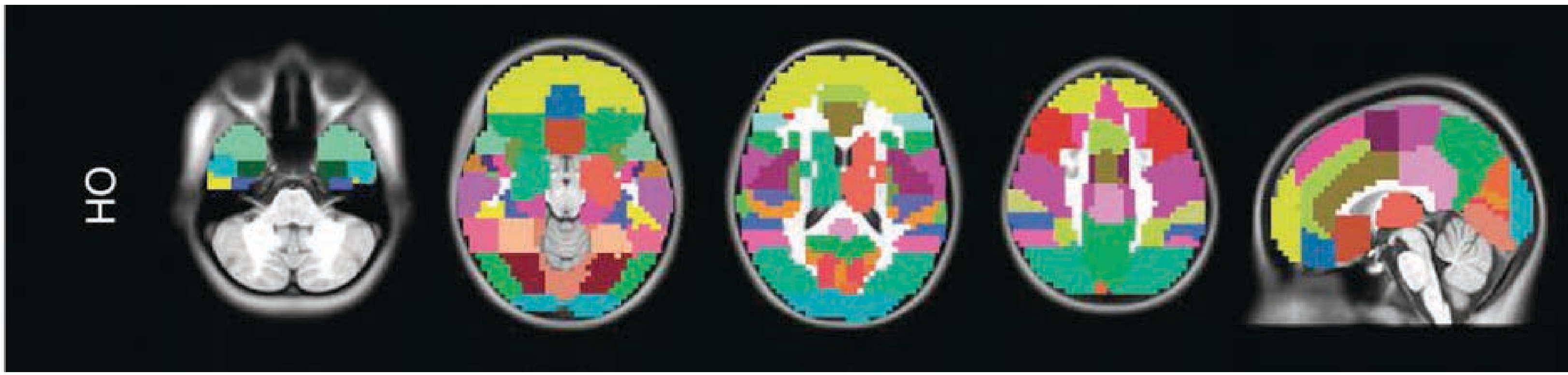


From (Cie et al., Cereb Cortex, 2014)

HO – the Harvard Oxford probabilistic atlas

Harvard-Oxford atlas
(Desikan et al., 2006)



LBPA40: the LONI Probabilistic Brain Atlas

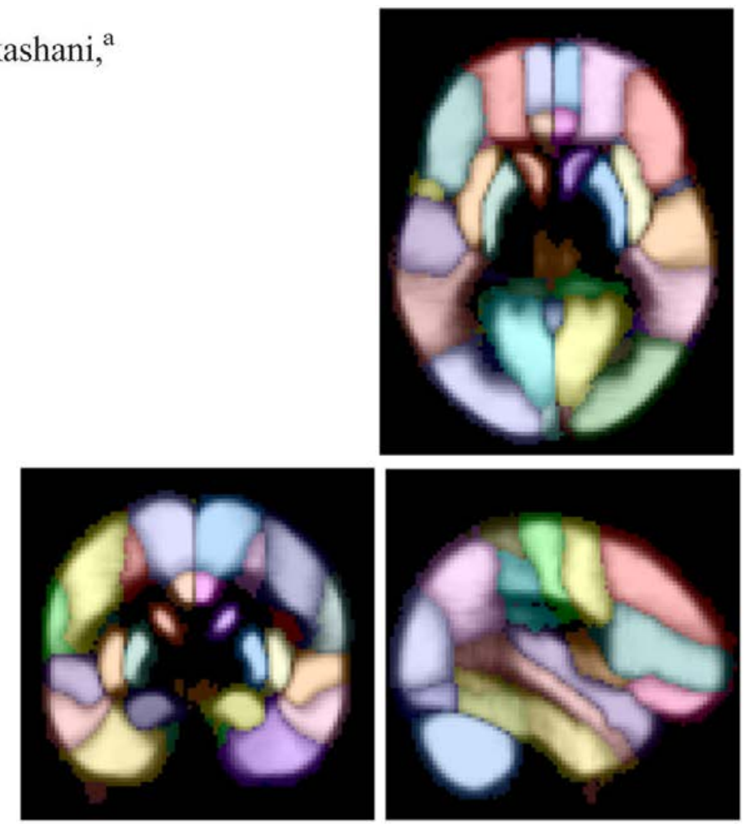
ELSEVIER

NeuroImage

www.elsevier.com/locate/ynimg
NeuroImage 39 (2008) 1064 – 1080

Construction of a 3D probabilistic atlas of human cortical structures

David W. Shattuck,[a,*] Mubeena Mirza,[a] Vitria Adisetiyo,[a] Cornelius Hojatkashani,[a] Georges Salamon,[b] Katherine L. Narr,[a] Russell A. Poldrack,[c] Robert M. Bilder,[c,d] and Arthur W. Toga[a]



- Build from 40 subjects
- **56 structures overall** (cortical + subcortical).
- Probabilistic
- In the MNI space.

FreeSurfer – Desikan-Killiany parcellation

Part of the **FreeSurfer** software:

ELSEVIER

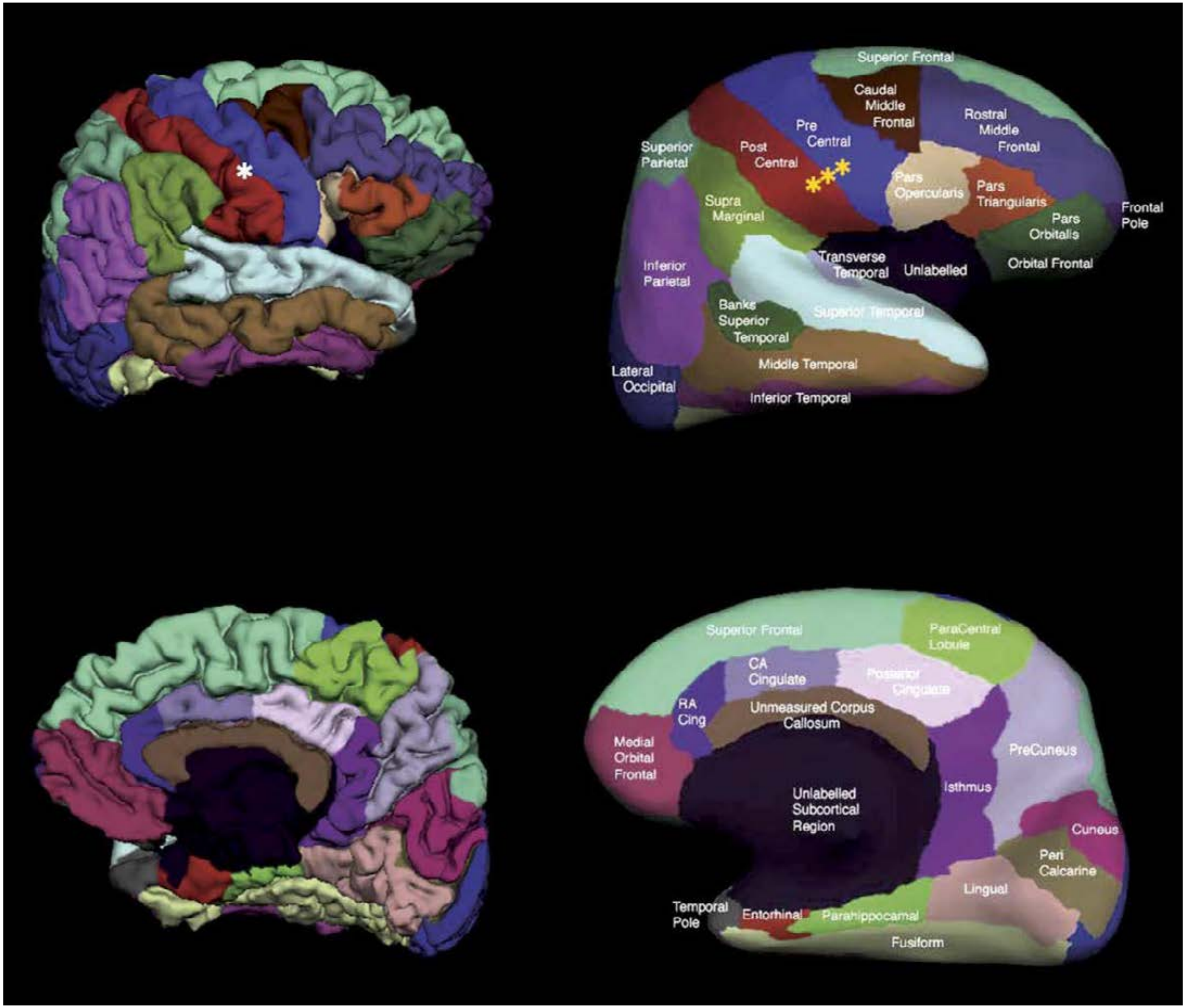
NeuroImage

www.elsevier.com/locate/ynimg
NeuroImage 31 (2006) 968 – 980

An automated labeling system for subdividing the human cerebral cortex on MRI scans into gyral based regions of interest

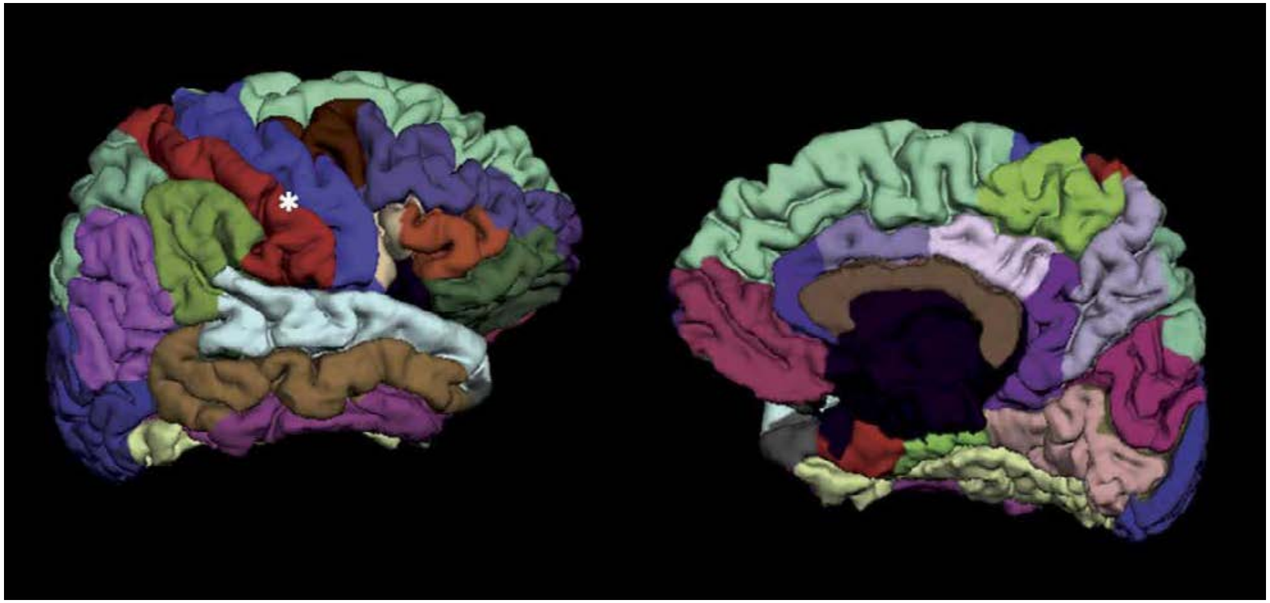
Rahul S. Desikan,[a] Florent Ségonne,[c] Bruce Fischl,[b,c] Brian T. Quinn,[b] Bradford C. Dickerson,[h] Deborah Blacker,[d] Randy L. Buckner,[b,e,f] Anders M. Dale,[g] R. Paul Maguire,[j] Bradley T. Hyman,[h] Marilyn S. Albert,[i] and Ronald J. Killiany[a,*]

Desikan-Killiany parcellation



Desikan-Killiany parcellation

- Built from 40 subjects manually delineated
- 68 cortical regions
- Probabilistic maps
- Freesurfer: adaptation to individual anatomy.



FreeSurfer: Destrieux parcellation

NeuroImage 53 (2010) 1–15

ELSEVIER

Contents lists available at ScienceDirect

NeuroImage

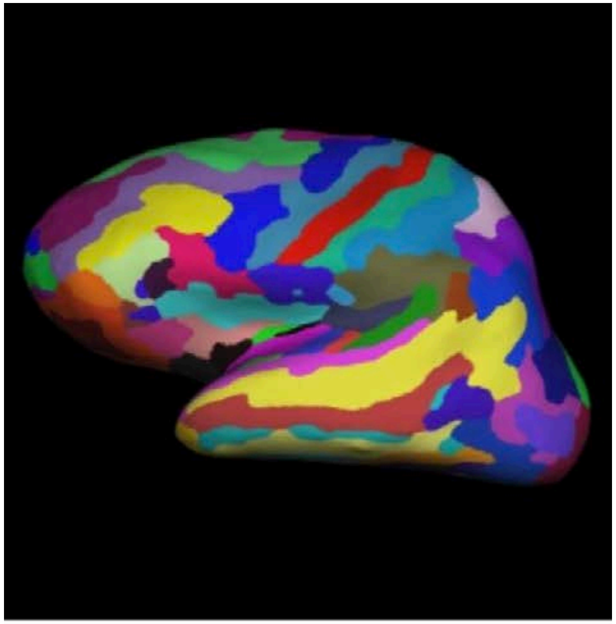
journal homepage: www.elsevier.com/locate/ynimg

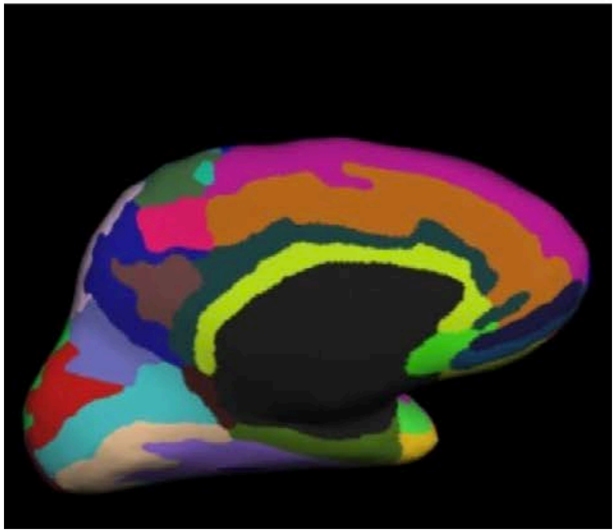
Automatic parcellation of human cortical gyri and sulci using standard anatomical nomenclature

Christophe Destrieux [a,b,c,d,*], Bruce Fischl [e,f], Anders Dale [g], Eric Halgren [g]

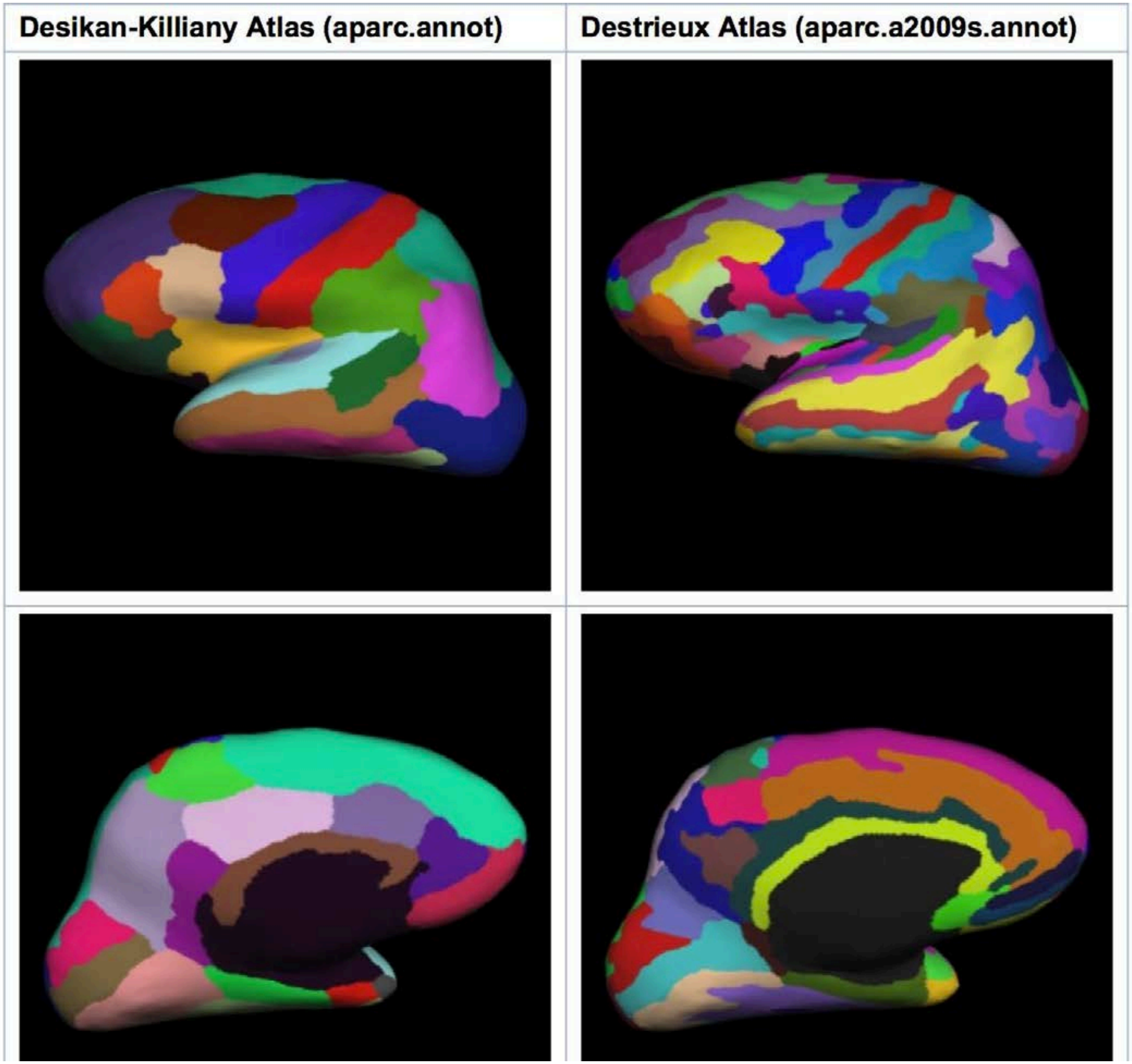
Destrieux parcellation

- Built from 12 subjects manually delineated
- 148 cortical regions
- (some) **Sulci as well as gyri**
- Probabilistic maps
- Freesurfer: adaptation to individual anatomy.
- Designed mostly for labelling anatomical structures





Destrieux vs. Desikan



BrainVisa: MarsAtlas

A model-based cortical parcellation (http://meca-brain.org/software)

◆ Human Brain Mapping 37:1573–1592 (2016) ◆

MarsAtlas: A Cortical Parcellation Atlas for Functional Mapping

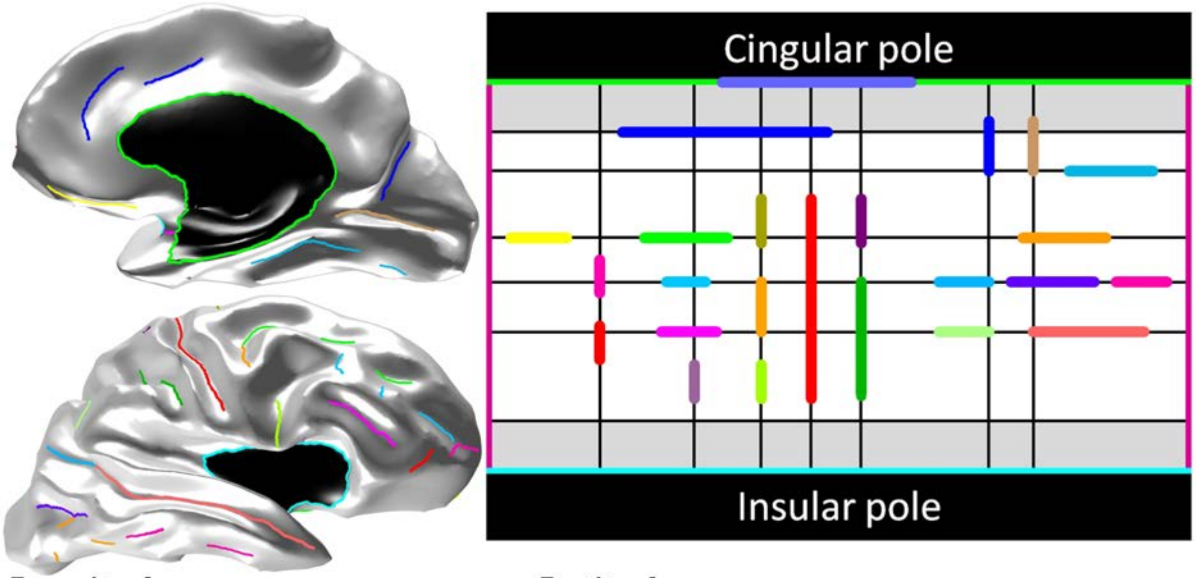
Guillaume Auzias,[1,2†] Olivier Coulon,[1,2†] and Andrea Brovelli[1*]

BrainVisa: MarsAtlas parcellation

A model of cortical organisation

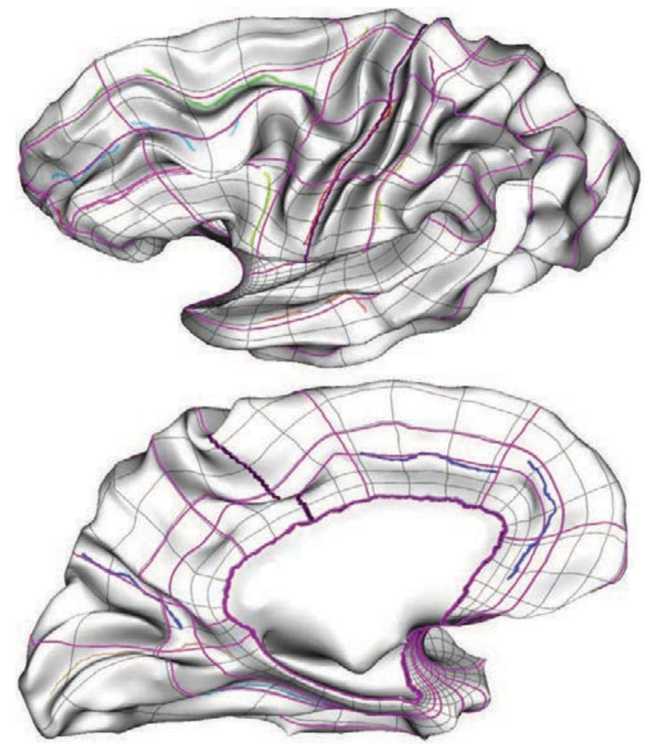
(Régis et al., Neurol Med Chir, 2005)

(Auzias et al., IEEE TMI, 2013)



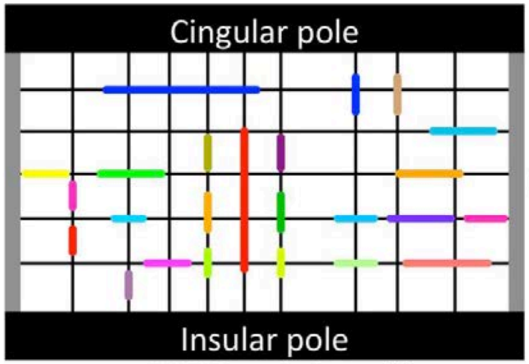
Longitudes
central sulcus
median precentral sulcus
superior precentral sulcus
inferior precentral sulcus
ascending ramus of the lateral fissure
marginal frontal sulcus
orbital frontal sulcus
calcarine fissure
parieto-occipital fissure
superior postcentral sulcus
inferior postcentral intraparietal superior sulcus

Latitudes
subcallosal sulcus
calloso-marginal anterior fissure
collateral fissure
olfactory sulcus
superior frontal sulcus
posterior occipito-temporal lateral sulcus
intermediate frontal sulcus
posterior terminal ascending branch of the superior temporal sulcus
posterior inferior temporal sulcus
anterior inferior temporal sulcus
inferior frontal sulcus
anterior terminal ascending branch of the superior temporal sulcus
superior temporal sulcus

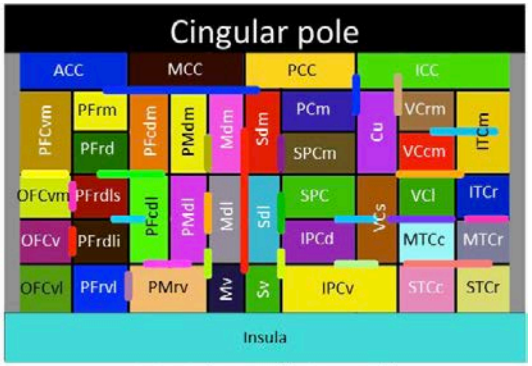


MarsAtlas

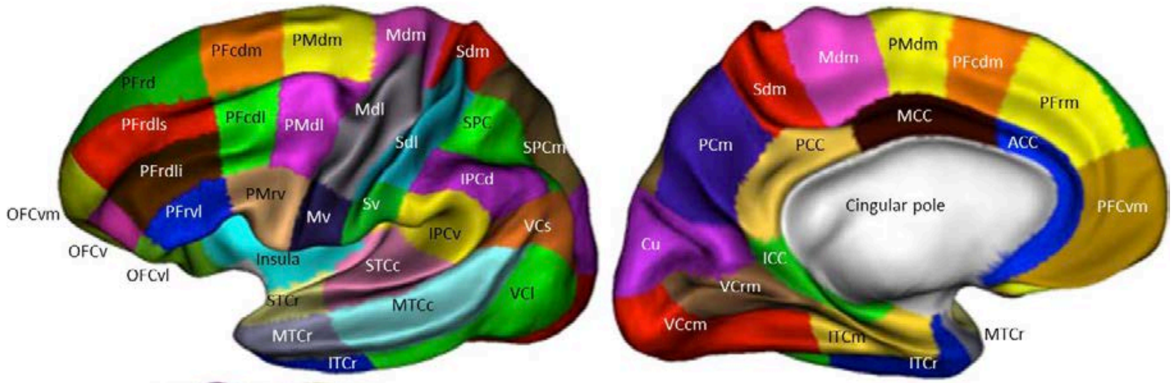
- Based on a model of cortical organisation
- Parameters of the model infered from a set of 62 subjects.
- 82 cortical regions
- Gyrus based with additional subdivisions.

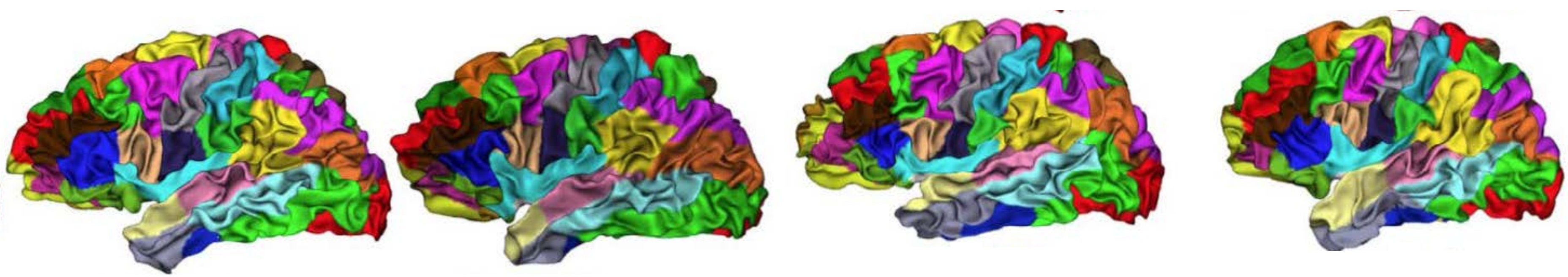


HIP-HOP organisation model



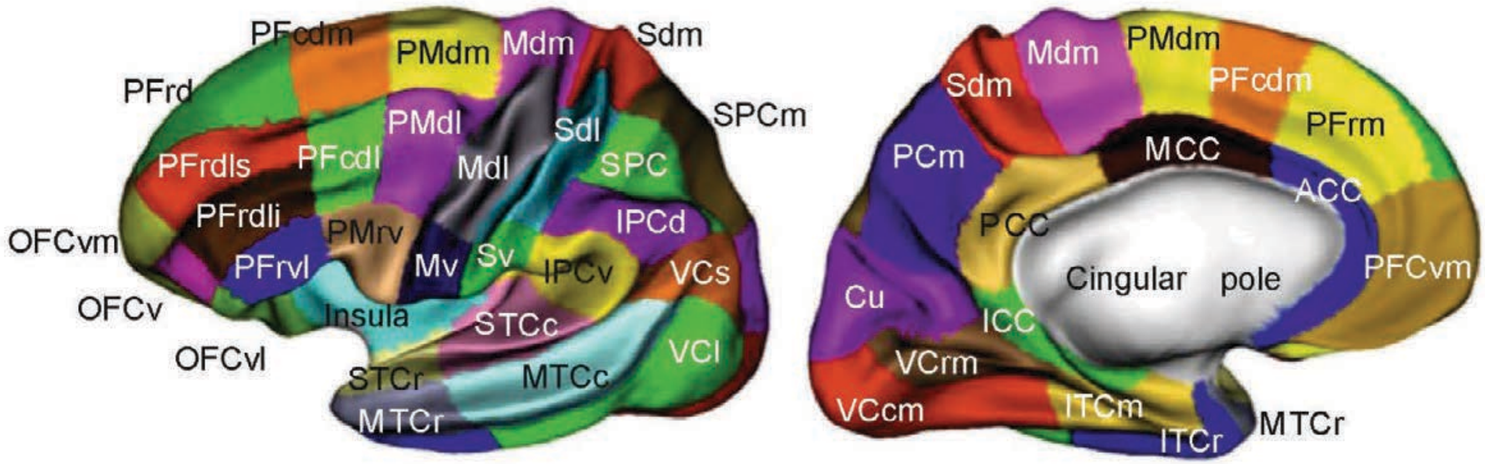
MarsAtlas parcellation model



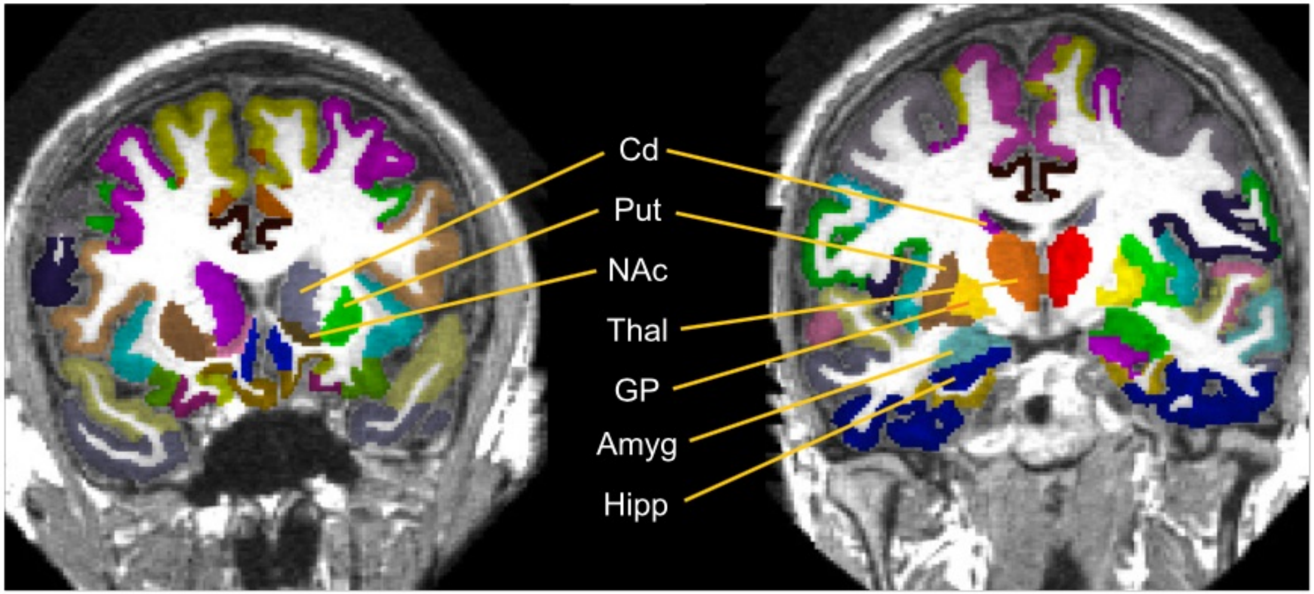


MarsAtlas

Surface based



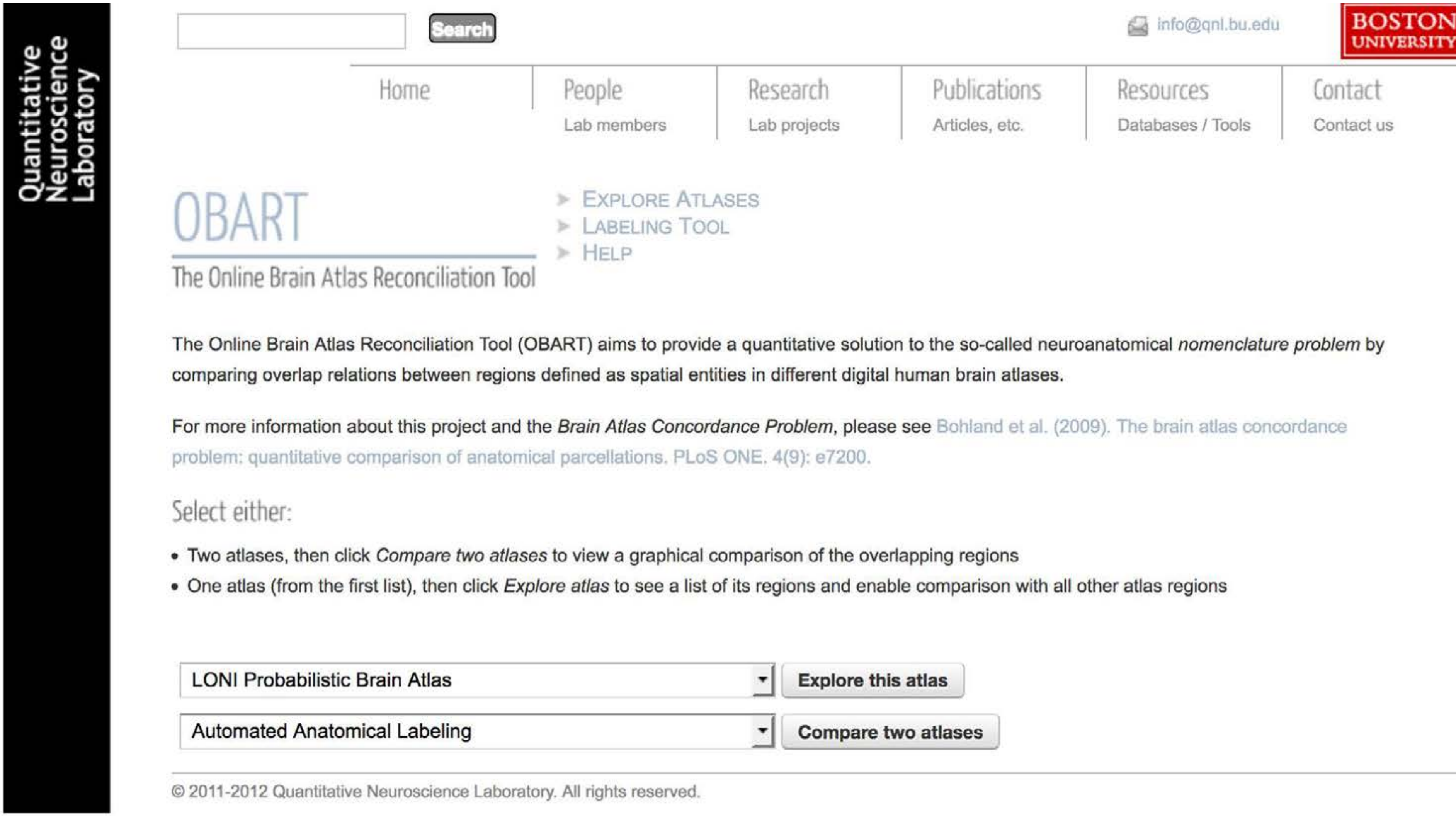
Volume based + subcortical (Brovelli et al., J of Neuroscience, 2017)



Comparing parcellations: OBART

The Online Brain Atlas Reconciliation Tool: http://qnl.bu.edu/obart

Bohland, J. W., Bokil, H., Allen, C. B., & Mitra, P. P. (2009). The Brain Atlas Concordance Problem: Quantitative Comparison of Anatomical Parcellations. *PLoS ONE*, *4*(9), e7200.



Comparing parcellations: OBART

Comparing overlapping regions from:

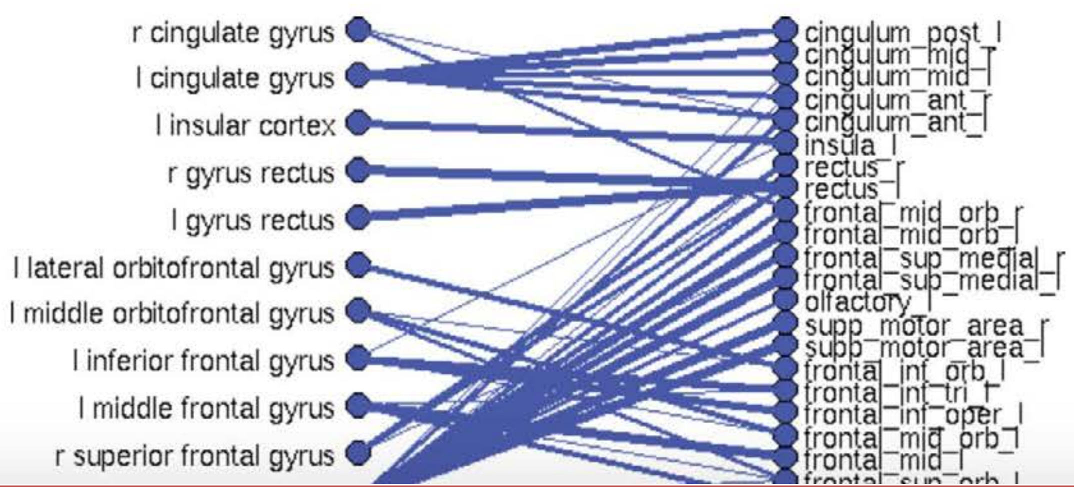
- LONI Probabilistic Brain Atlas (LPBA)
- Automated Anatomical Labeling (AAL)

Adjust the slider to set the edge threshold:

The threshold represents the minimum percentage of overlap (relative to either of the two regions) that will result in an edge being drawn between those regions. Thus think of the edges as indicating spatial overlap, and the threshold as your way of "removing noise" from a complicated pattern of overlapping region pairs.

When the graph is thresholded, it may break into multiple *connected components*, which are color coded. A connected component is a set of nodes (regions) that are isolated from the other sets in the graph (you can't find a path between that component and other components by following the edges). You can think of each connected component as a pair of sets of regions such that the sum of the regions on the left is approximately spatially equivalent to the sum of the regions on the right (given your chosen threshold).

25 **Refresh Threshold**

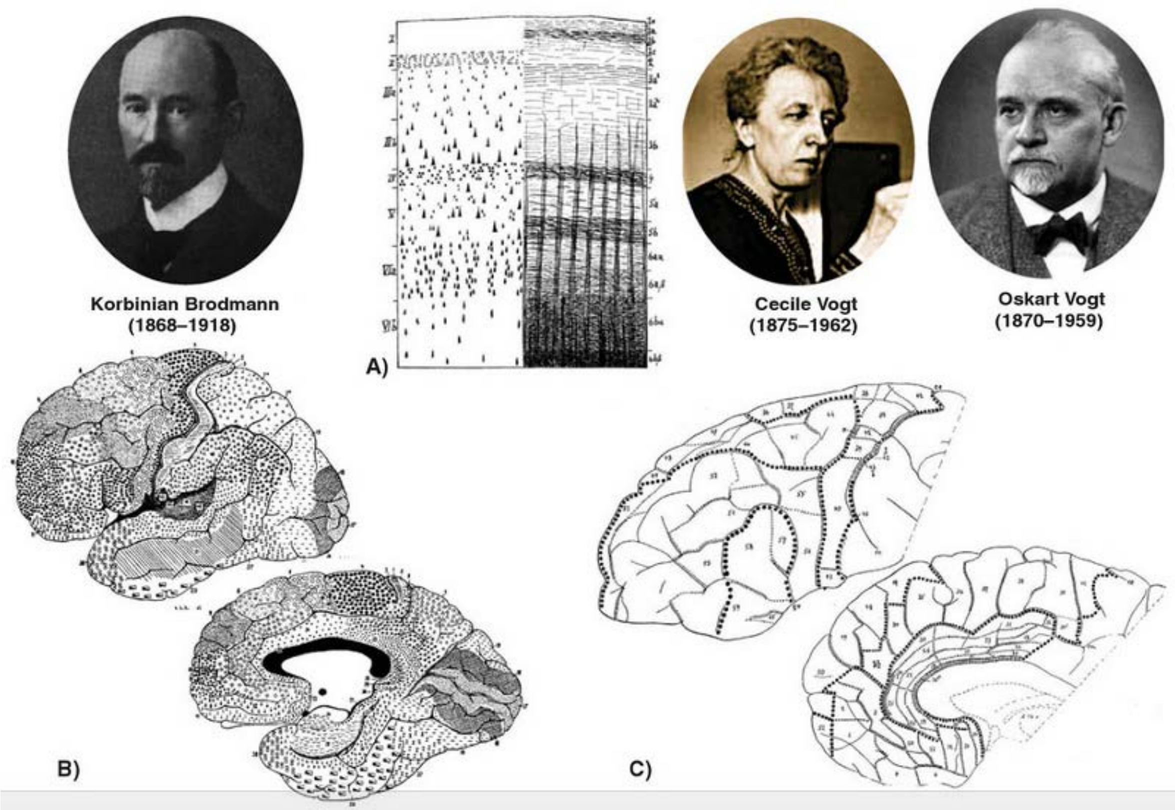


Building parcellations from micro-structure

Micro-structure

Grey matter micro-structure differenciate cortical areas:

- Size and density of cell nucleus : cytoarchitectony
- Size, density, arrangement of axones: myeloarchitectony



From (Catani & de Schotten, 2012)

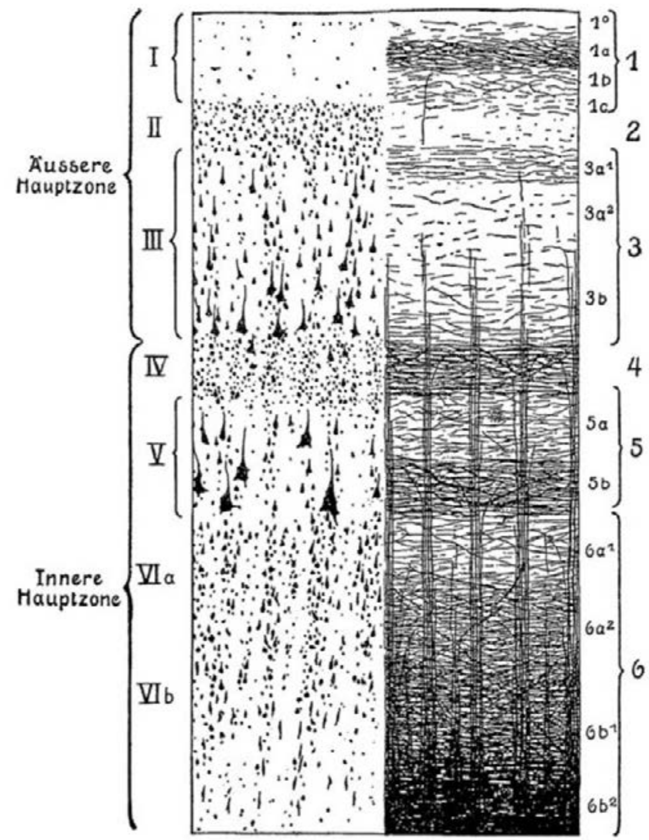
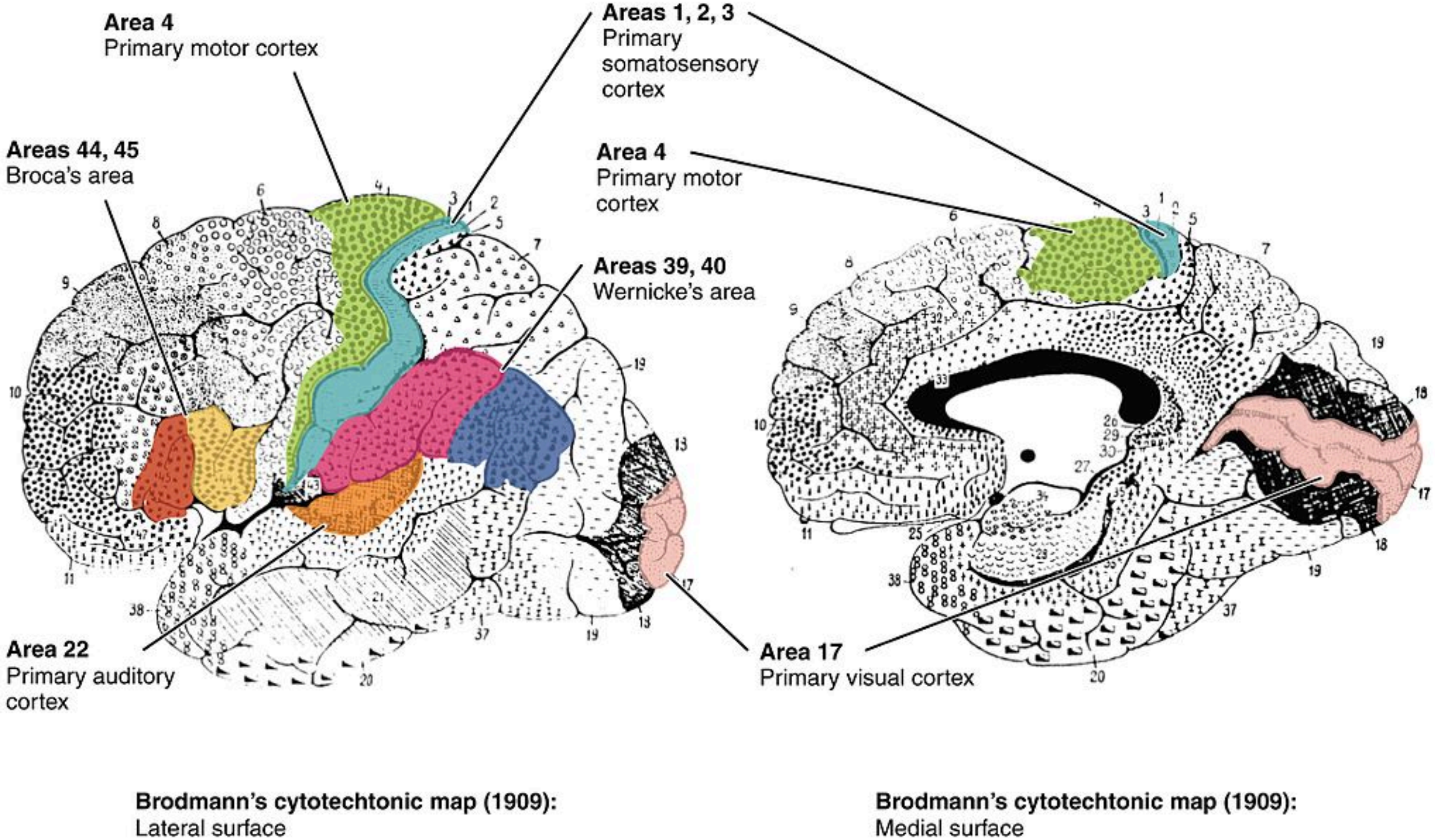


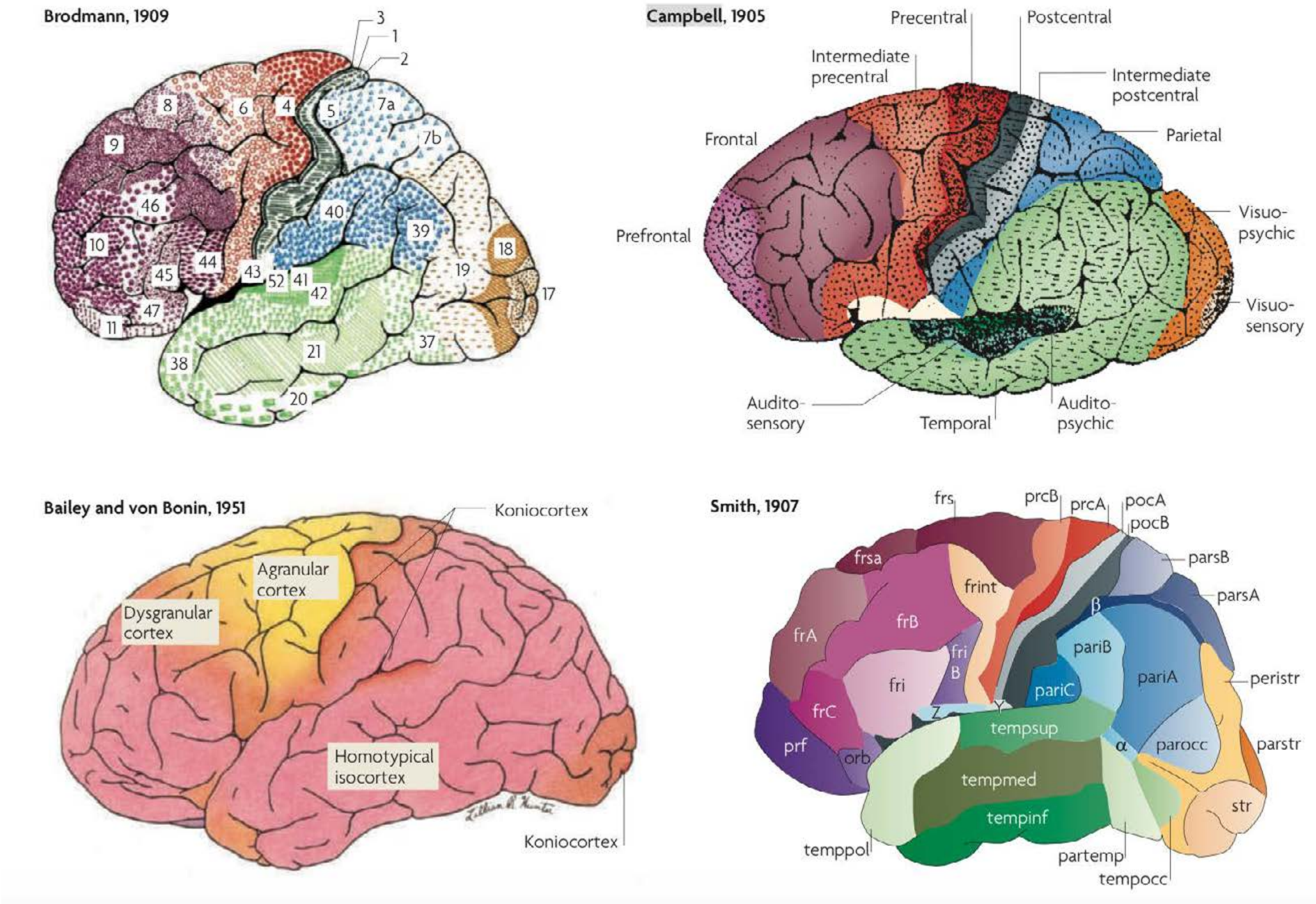
Fig. 3 Vogt's (1903) basic schemes of the cytoarchitectonic layers (designated with *Roman numbers*), and the myeloarchitectonic layers (designated with *Arabic numbers*)

Architectonic atlases



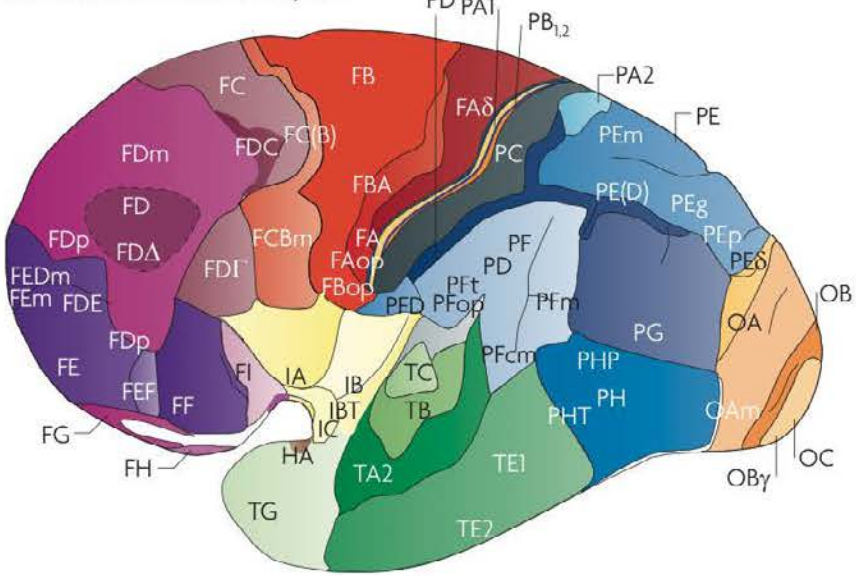
Brodmann's Atlas, 52 areas/hemisphere

Architectonic atlases

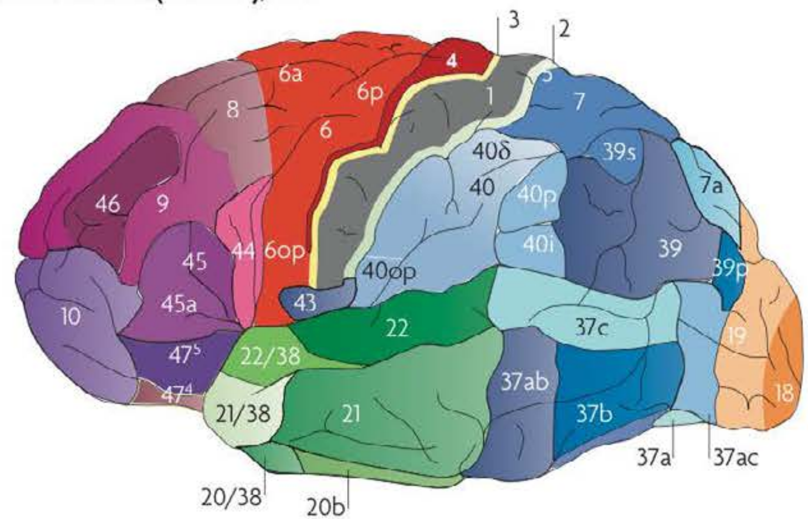


Architectonic atlases

von Economo and Koskinas, 1925



Russian school (Sarkisov), 1949

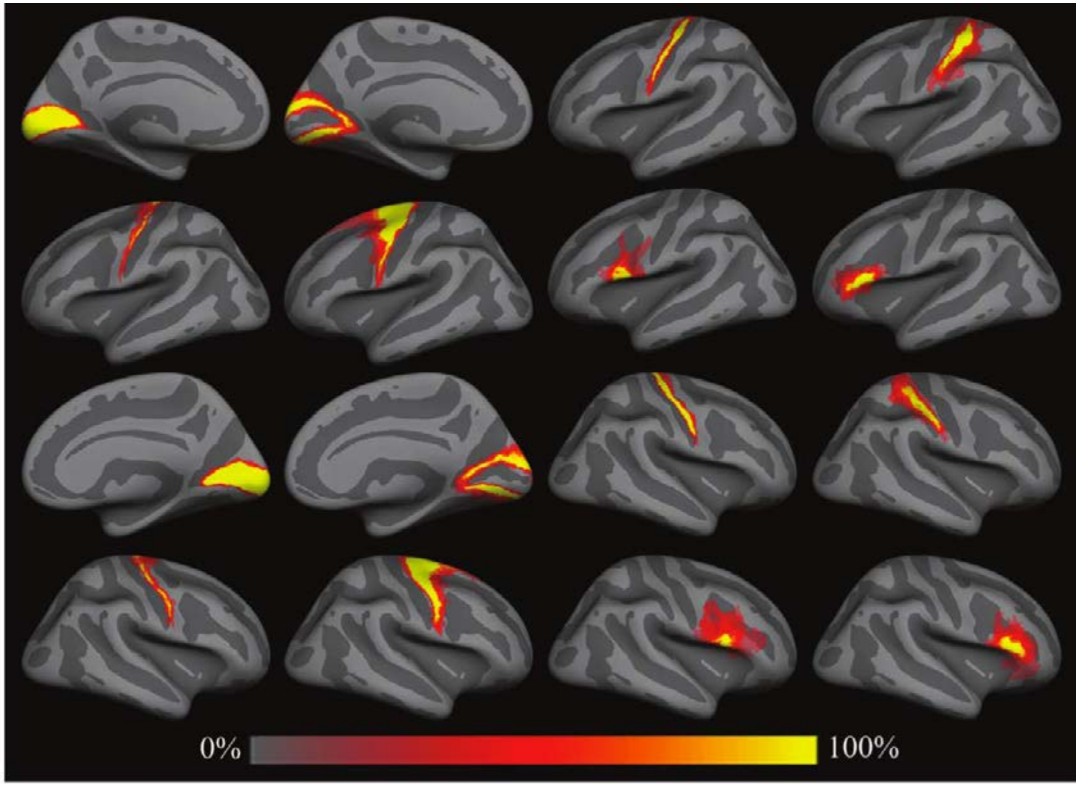


How to explain differences between atlases ?

- Inter-individual variability
- Methodological differences

What is the link between architectony and the observable macro-anatomy ?

Macro-anatomy and micro-structure



(Fischl et al., Cereb Cortex, 2008)

The border between primary motor area 4 and primary somatosensory area 3a is always located in the depth of the anterior wall of the central sulcus (Brodmann, 1909; Geyer et al., 1999).

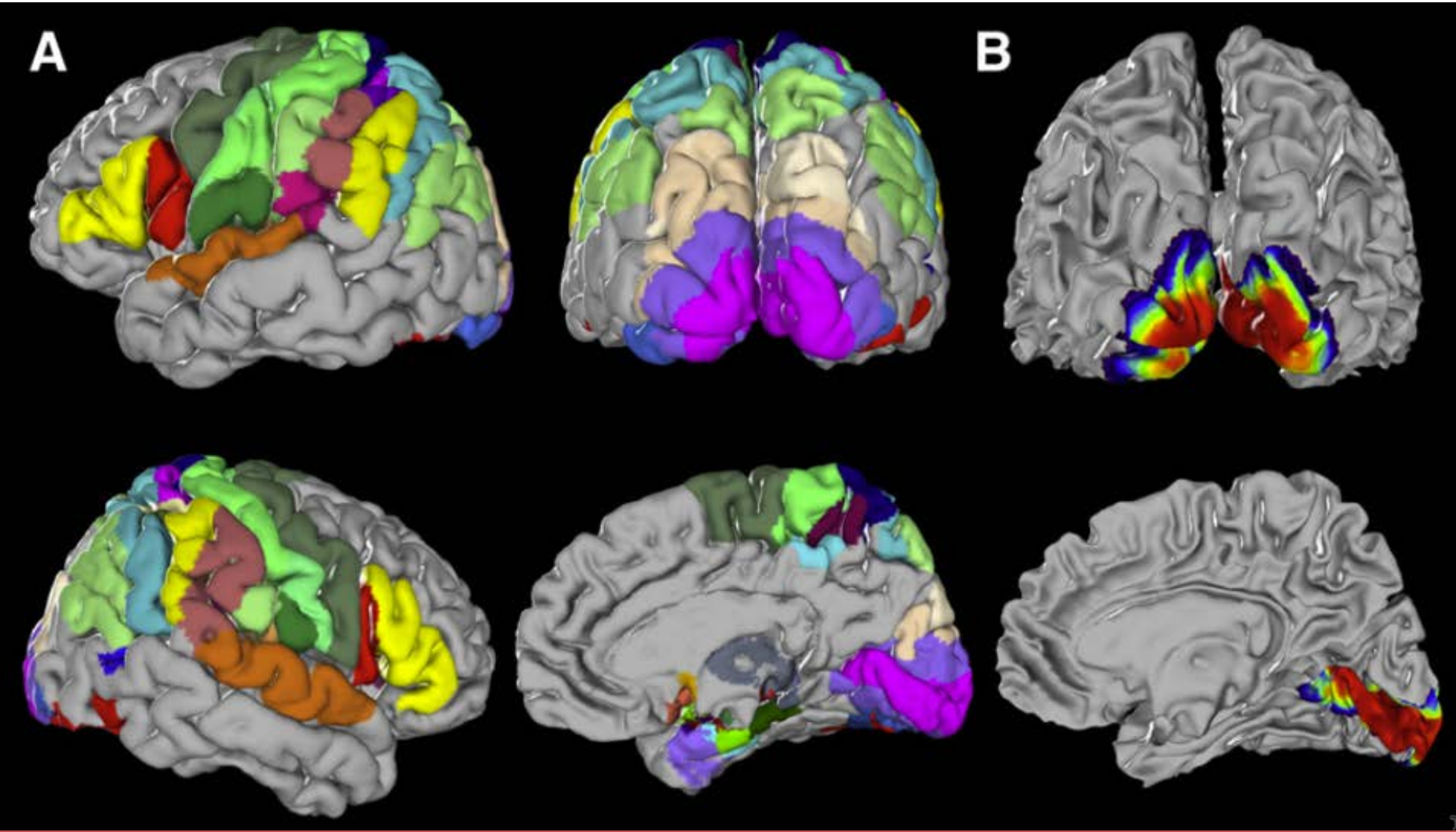
The primary visual cortex area 17 is always found within the calcarine sulcus (Amunts et al., 2000; Fischl et al., 2008; Hinds et al., 2008).

The position of Broca's region, consisting of cytoarchitectonic areas 44 and 45 (Amunts et al., 1999), is always on the caudal aspect of the inferior frontal gyrus (Fischl et al., 2009).

The JuBrain Cytoarchitectonic atlas

(Eickhoff et al., Neuroimage, 2005; Zilles & Amunts, Nat. Rev. Neurosci., 2010)

http://www. fz-juelich.de/JuBrain/EN/_node.html



The JuBrain Cytoarchitectonic atlas

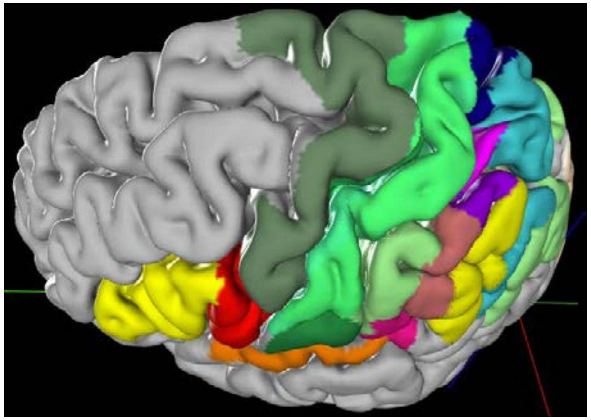
- Made from 10 post-mortem brains
- 3D reconstructed
- 52 cortical areas
- Normalized to MNI space

  ⇒ probability map for each area
  ⇒ parcellation available with Max Probability Map

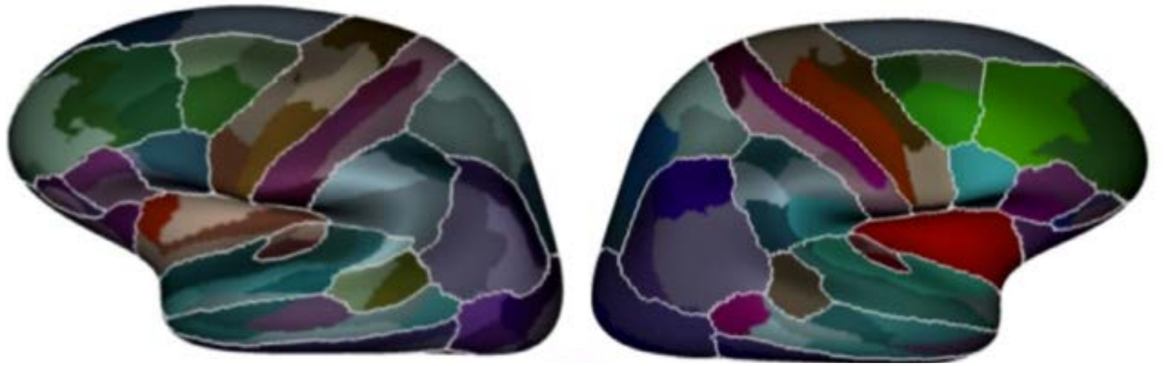
- Available with FSL and SPM's Anatomy Toolbox

- Some Limitations:
  - Does not cover the whole cortex (≈20%)
  - Cytoarchitectony is not necessarily the final answer to parcellation

Cytoarchitectony, connectivity, and function



http://www. fz-juelich.de/JuBrain/EN/_node.html



(Roca et al., Med Image Analysis, 2016)

(Cros et al., Neuroimage 2013):
Architectony-defined left area 44 (Broca's region) can be split in 5 sub-clusters with different functional characteristics and resting state connectivity

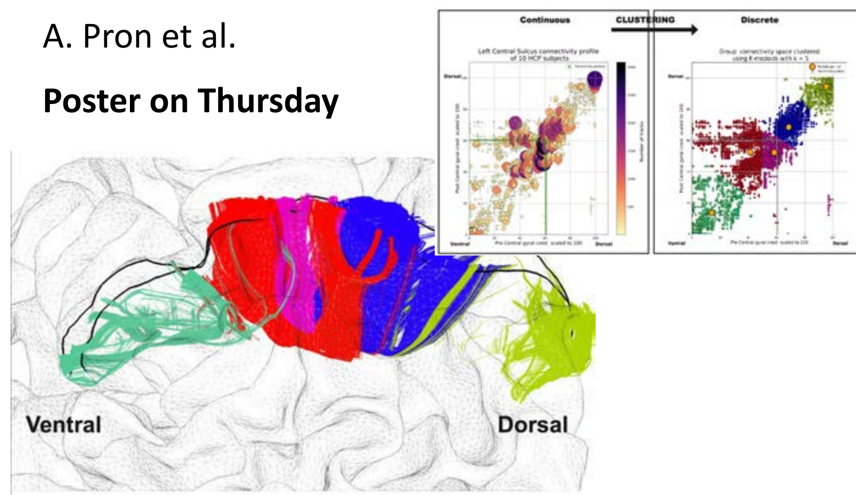
(Passingham et al., Nature reviews, 2002):

each cortical area has a unique pattern of cortico-cortical connections ('connectional fingerprint')

Dense and structured representatins of U-shape fiber connectivity inthe central sulcus

A. Pron et al.

Poster on Thursday

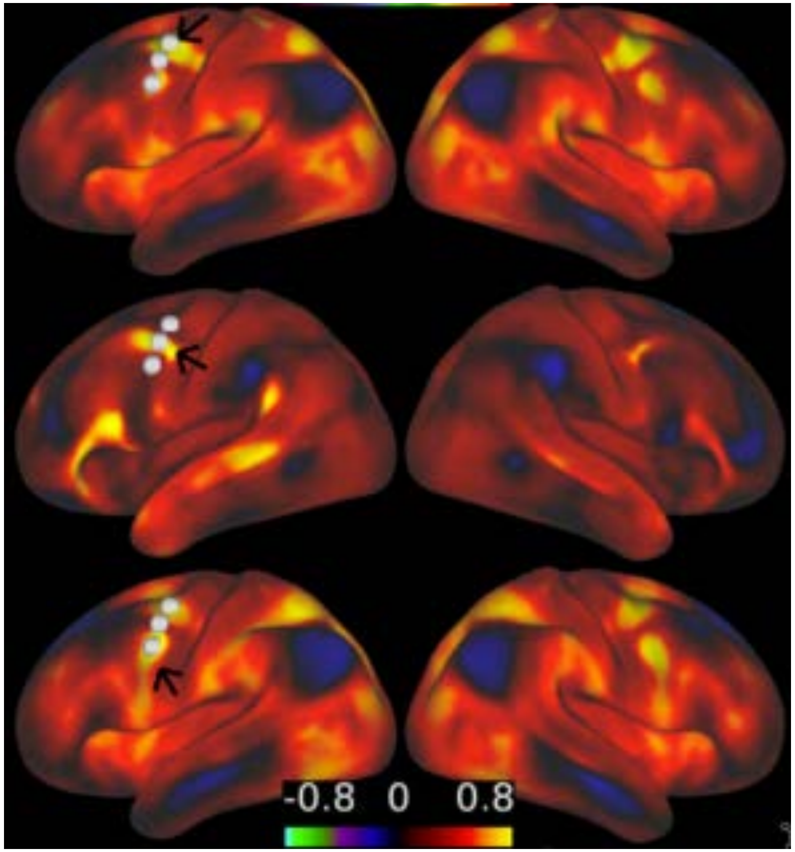


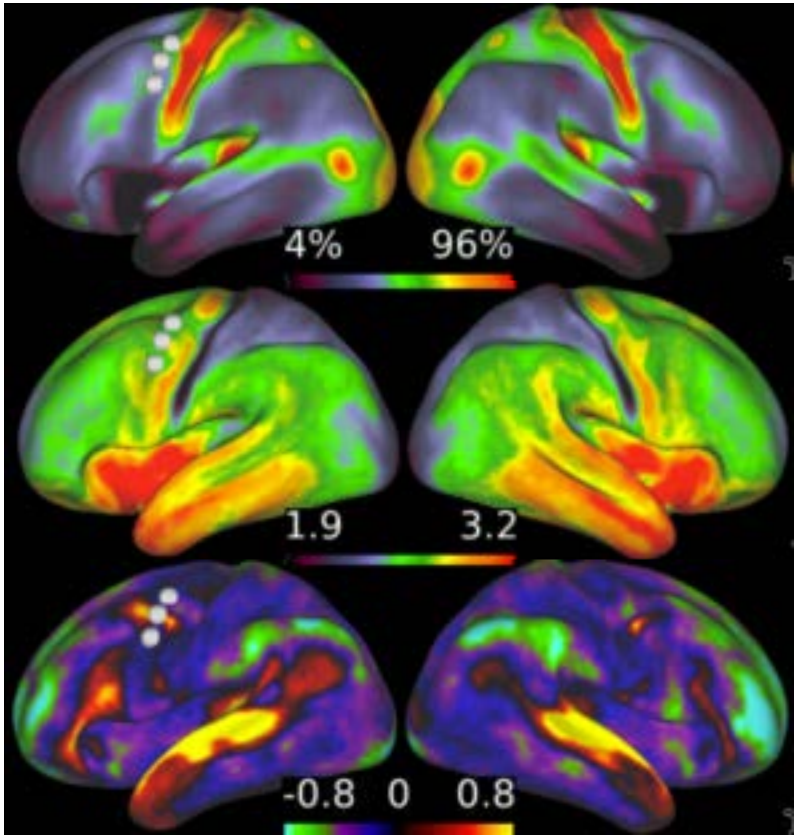
Building parcellations from multi-modal information

Multi-modal maps

Many different cortical maps can be build from MR acquisitions:

(Glasser et al., Nature, 2016)



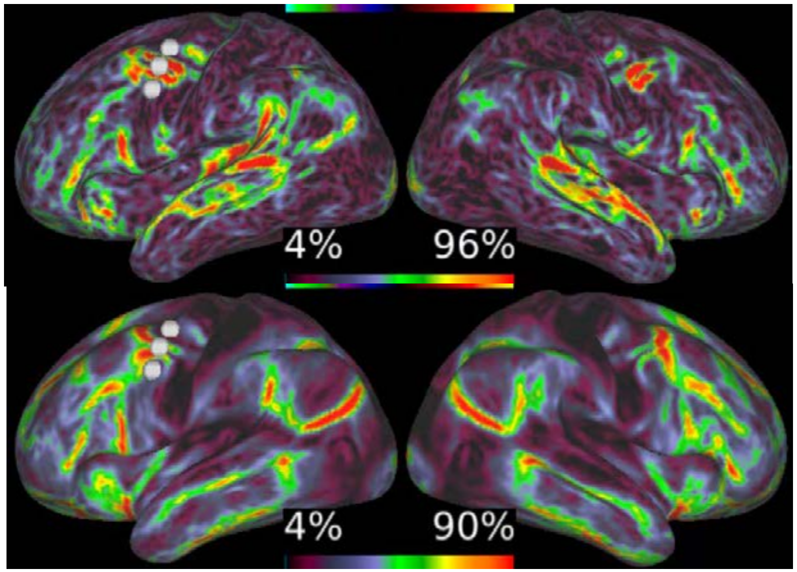


Resting state functional connectivity maps

Multi-modal gradient maps

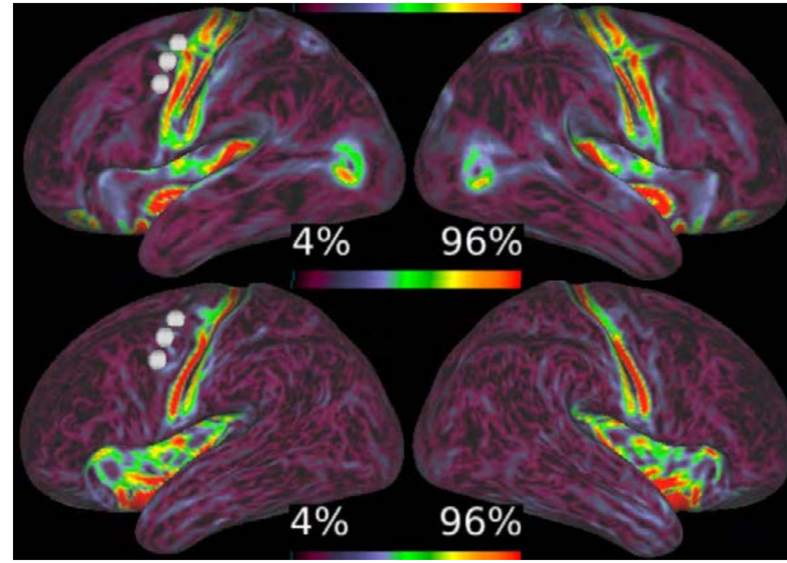
fMRI task

Functional connectivity



Myelin

CT



Borders between regions are delimited based on the concordance of gradient maps across several modalities.

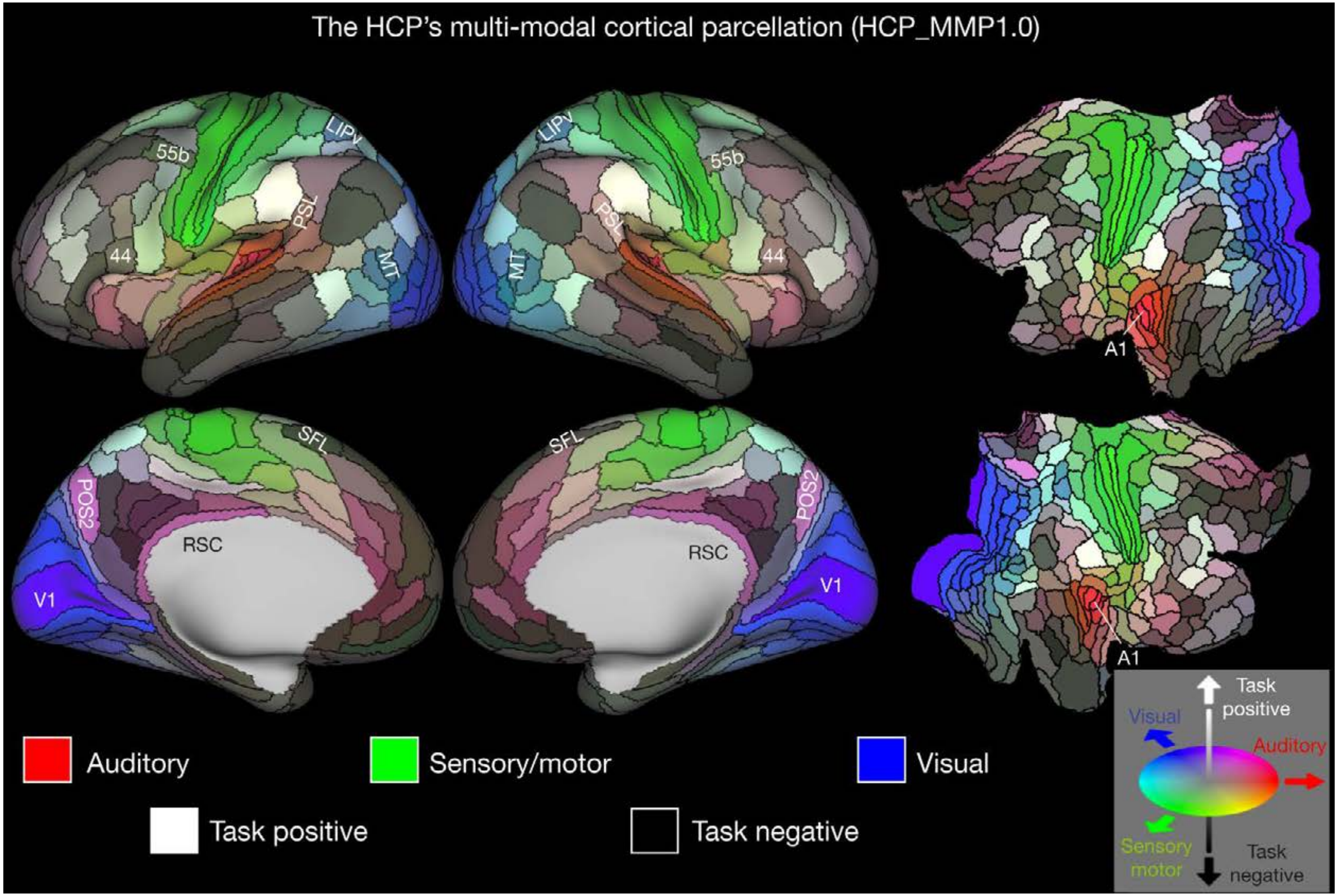
doi:10.1038/nature18933

Nature, 2016

A multi-modal parcellation of human cerebral cortex

Matthew F. Glasser[1], Timothy S. Coalson[1]*, Emma C. Robinson[2,3]*, Carl D. Hacker[4]*, John Harwell[1], Essa Yacoub[5], Kamil Ugurbil[5], Jesper Andersson[2], Christian F. Beckmann[6,7], Mark Jenkinson[2], Stephen M. Smith[2] & David C. Van Essen[1]

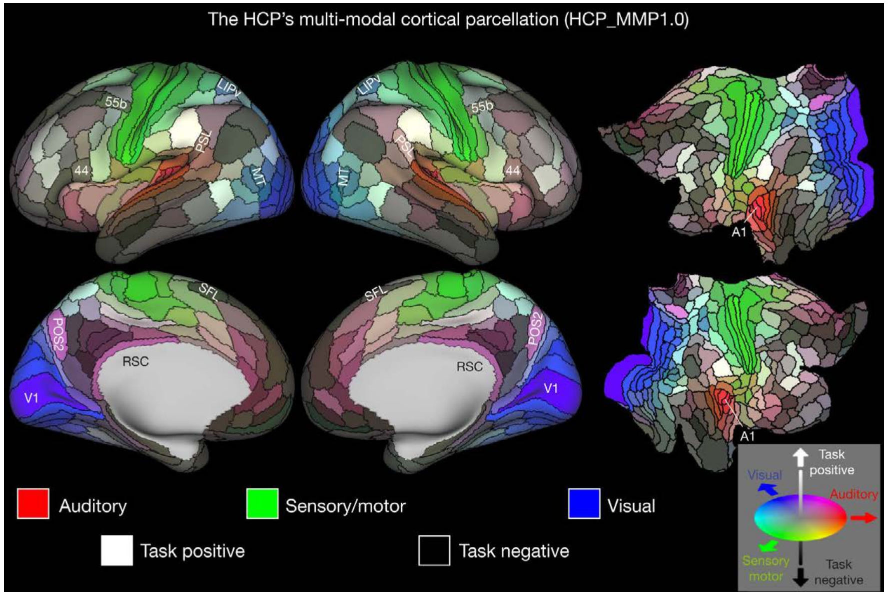
HCP's multi-modal parcellation



(Glasser et al., 2016)

HCP's multi-modal parcellation

- 180 areas per hemisphere
- Multi-modal chacarerization of each area
- Possible generalization to new subjects via a classication method



But :

- New individual without multi-modal information ? (registration based only)
- Very heterogeneous size of regions.
- Some areas are not suitable for structural connectivity inference (e.g. 'gyral bias' and sensori-motor cortex, or superior temporal sulcus).
- Are there possible subdivisions using other fMRI task-related acquisitions ?

Building random/high resolution parcellations

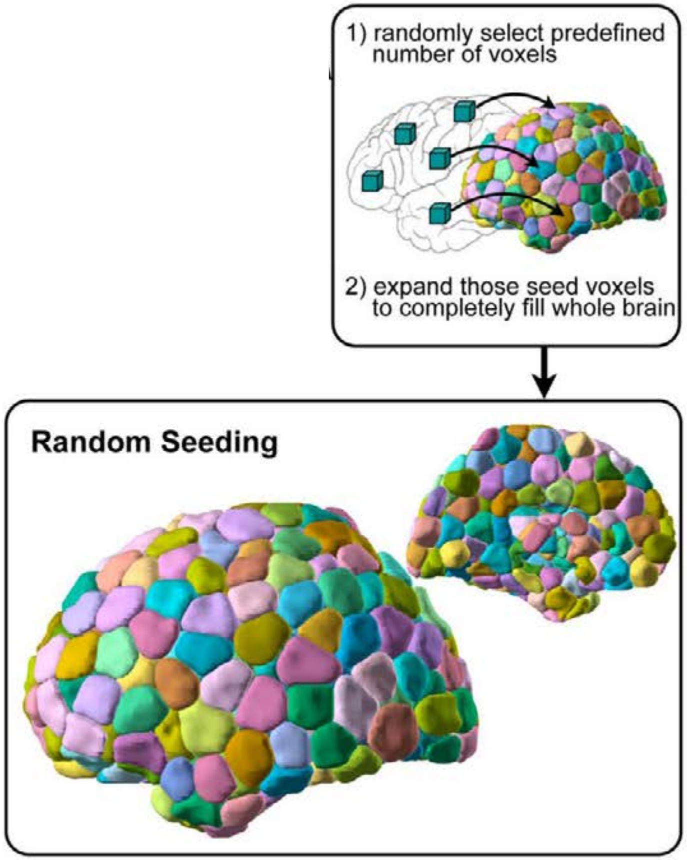
Limited number of regions

- Most parcellation scheme cannot go above 200 regions.
- But we might want to use >500 regions
- How to increase the number of regions ?

Limited number of regions

- Most parcellation scheme cannot go above 200 regions.
- But we might want to use >500 regions
- How to increase the number of regions ?

1 – build a random parcellation



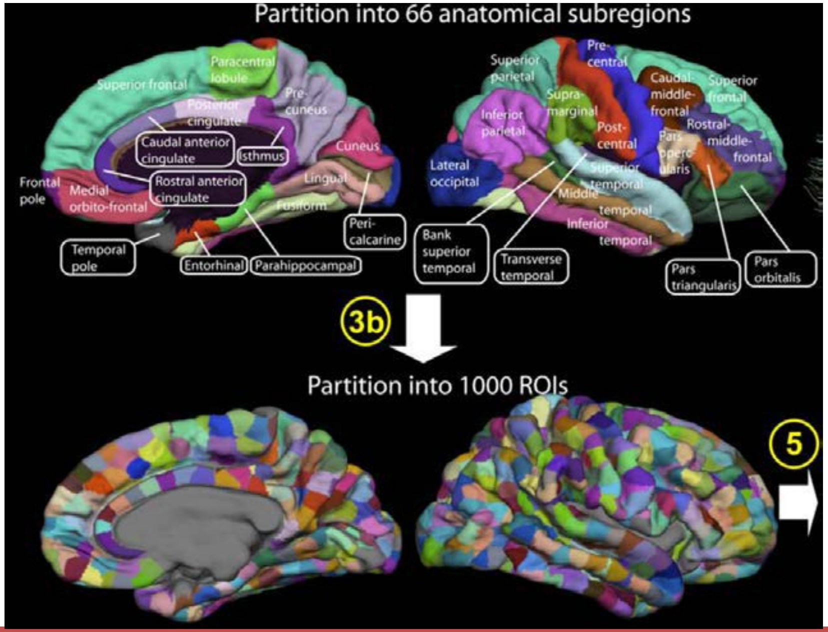
(Park et al., *PLoS ONE*, *8*(9), e74935.)

Limited number of regions

- Most parcellation scheme cannot go above 200 regions.
- But we might want to use >500 regions
- How to increase the number of regions ?

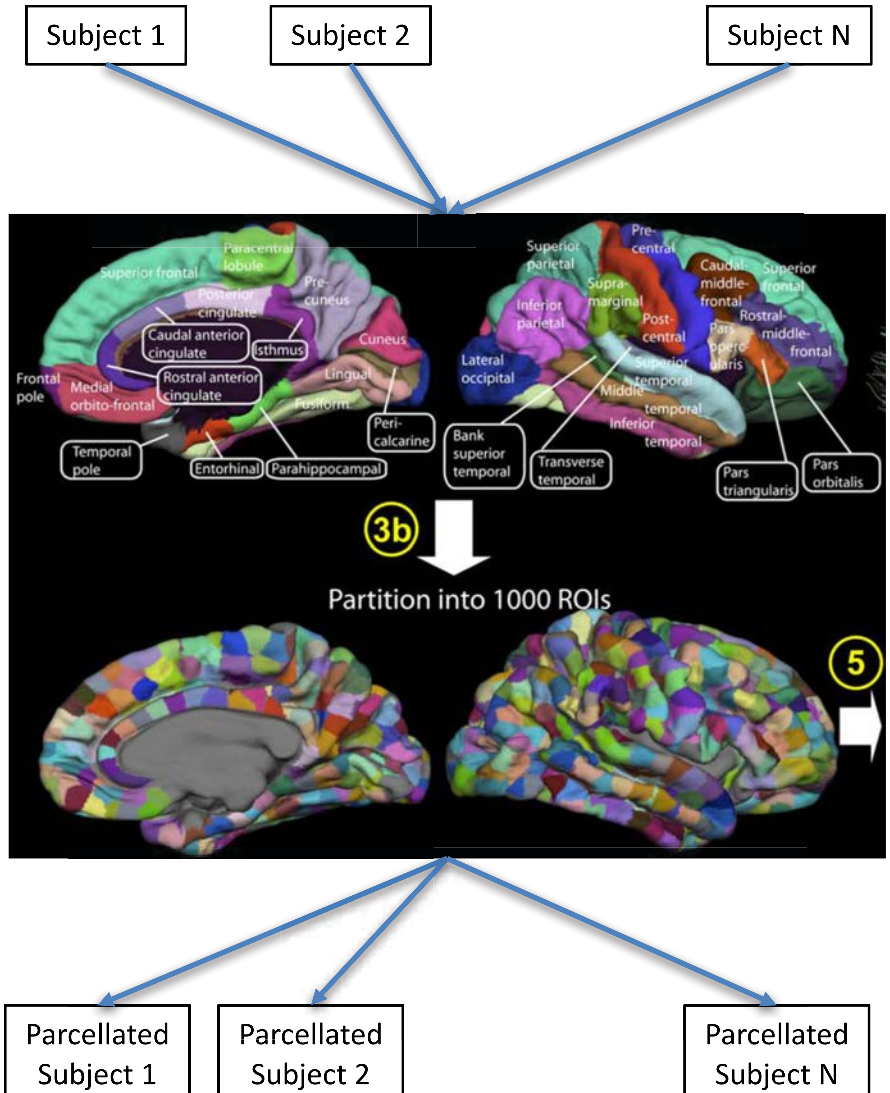
1 – build a random parcellation

2 – subdivide an existing atlas (e.g. Hagmann et al., 2008)



High resolution parcellation

(Hagmann et al., PLoS Biology, 2008), (van den Heuvel & Sporns, J. Neuroscience, 2011), (Fornito et al., Front. In System Neuroscience, 2010)



Advantages:

- High number of regions
- Size homogeneity
- Partial fit with local anatomy depending on the initial parcellation

Limitations:

- No nomenclature / anatomical labelling of regions

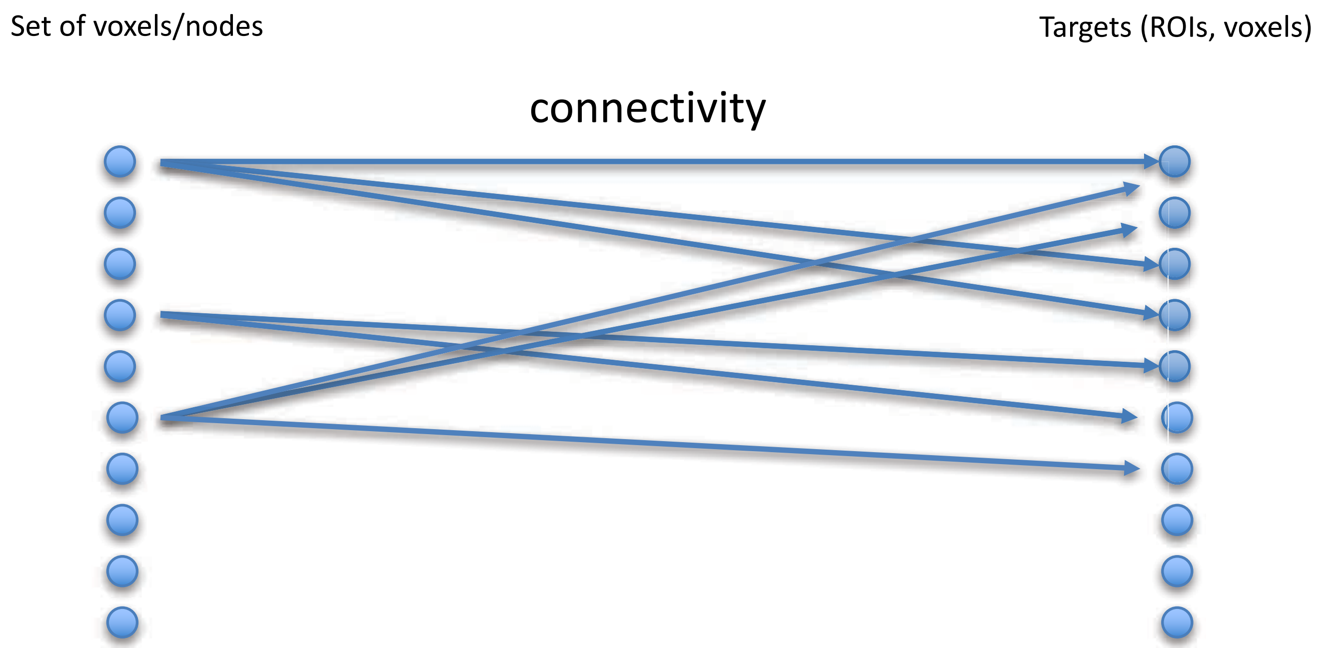
Adapted to functional connectomics

Building parcellations from connectivity

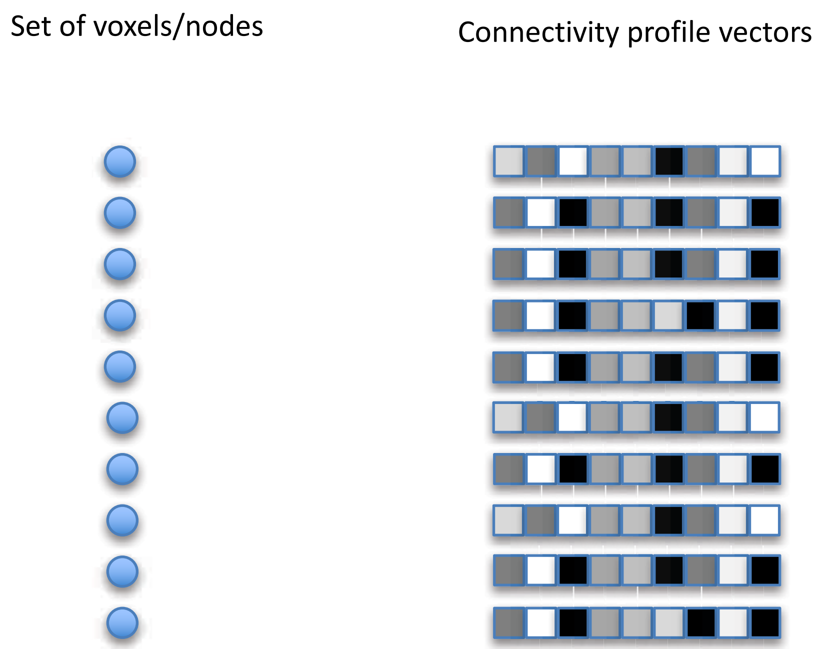
Motivations

- One might want to build a parcellation with cortical units showing an optimal level of connectional segregation
- The connectional fingerprint hypothesis (Passingham et al., 2002) suggest an in-vivo access to cortical areas (otherwise accessible post-mortem).
- Connectivity might even be a way to define parcellation with more fine-grained subdivisions than classical cytoarchitectonic mapping (e.g. Clos et al., 2013; left area 44)
- This led to methods that parcellate regions of interest, or the entire cortex, based on connectivity.
- Connectivity information can be structural (Johansen-Berg et al., PNAS 2004; Behrens et al., Nat Neuroscience, 2003; Wiegell et al., Neuroimage, 2003; Jbabdi et al., Neuroimage 2009; Roca et al., MedImA, 2016) or functional (Craddock et al. Hum Brain Map, 2012; van den Heuvel et al., PLoS One, 2008; Mezer et al., Neuroimage, 2009; Smith et al., PNAS, 2009; Thirion et al., Hum Brain Mapp, 2006)

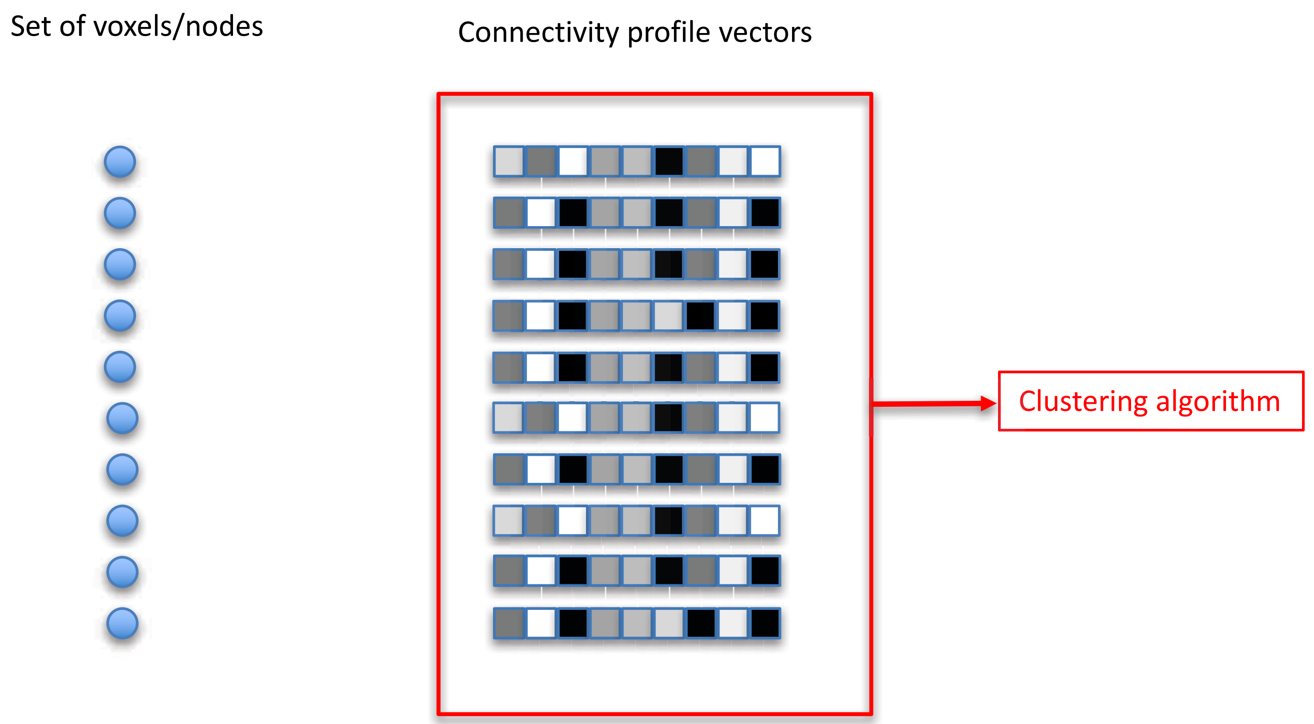
General principle



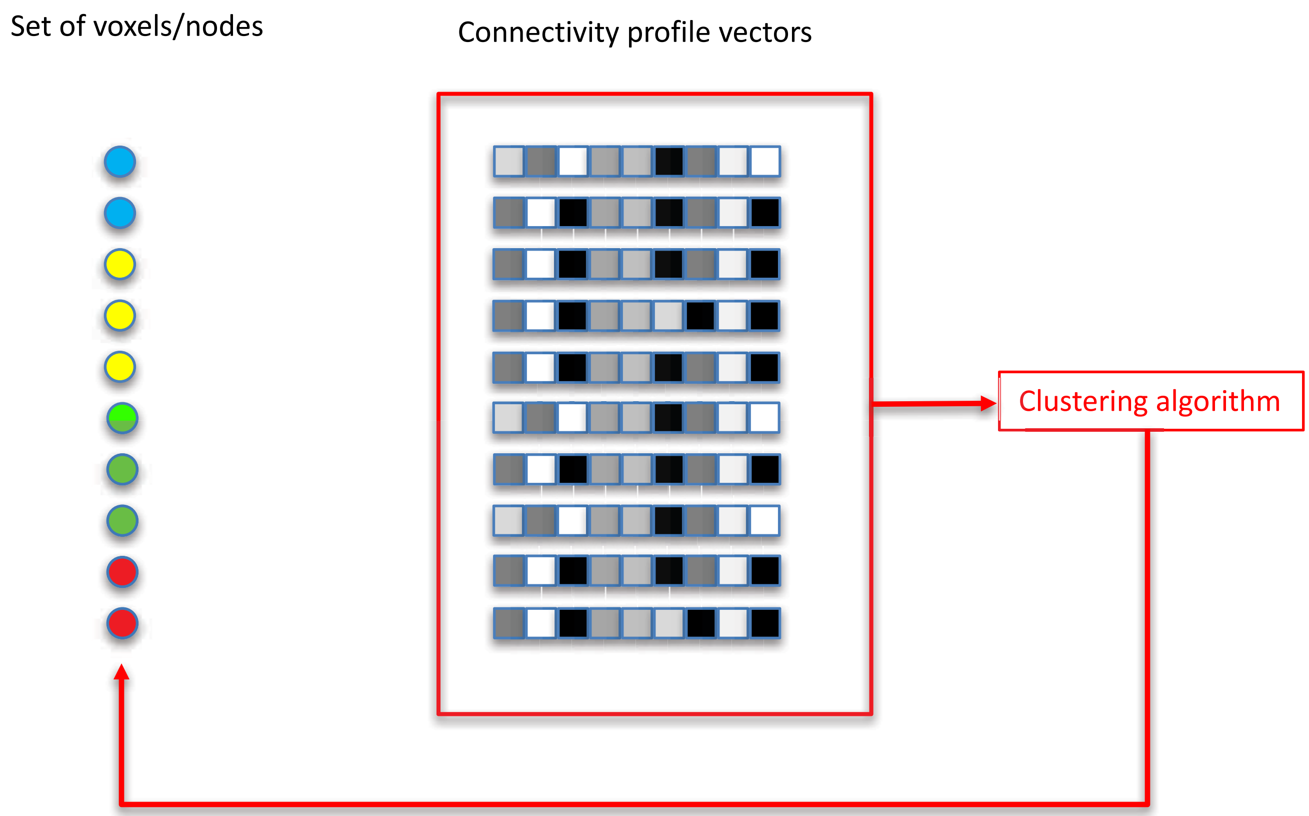
General principle



General principle

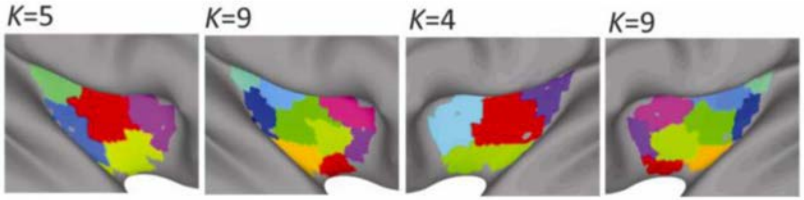


General principle



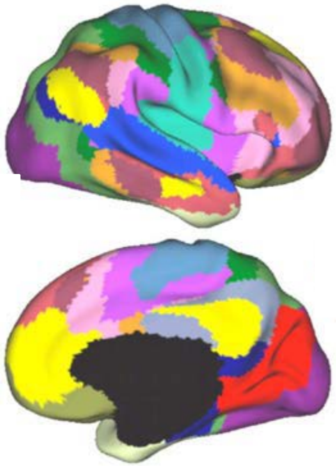
Warnings, comments

- Different clustering algorithm → different parcellations
- Number of cluster: a parameter for most clustering techniques, unsolved. Different number → different parcellations
- No consensus yet
- Might be early for structural connectivity (quantification of connection strength, gyral bias, reliability of tractography, dominance of large bundles)



right and left insula, (Kelly et al., 2012)

- Whole brain connectivity-based parcellation can be a way to compute connectivity networks without an initial parcellation (Yeo et al., Journal of Neurophysiology, 2011)



Thank you for listening

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Questions ?