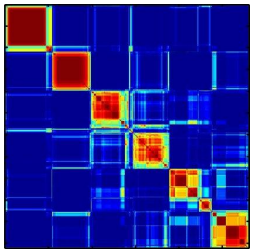
Université de Montréal

Pierre Bellec
Département de Psychologie
pierre.bellec@criugm.qc.ca

Functional brain Parcellation



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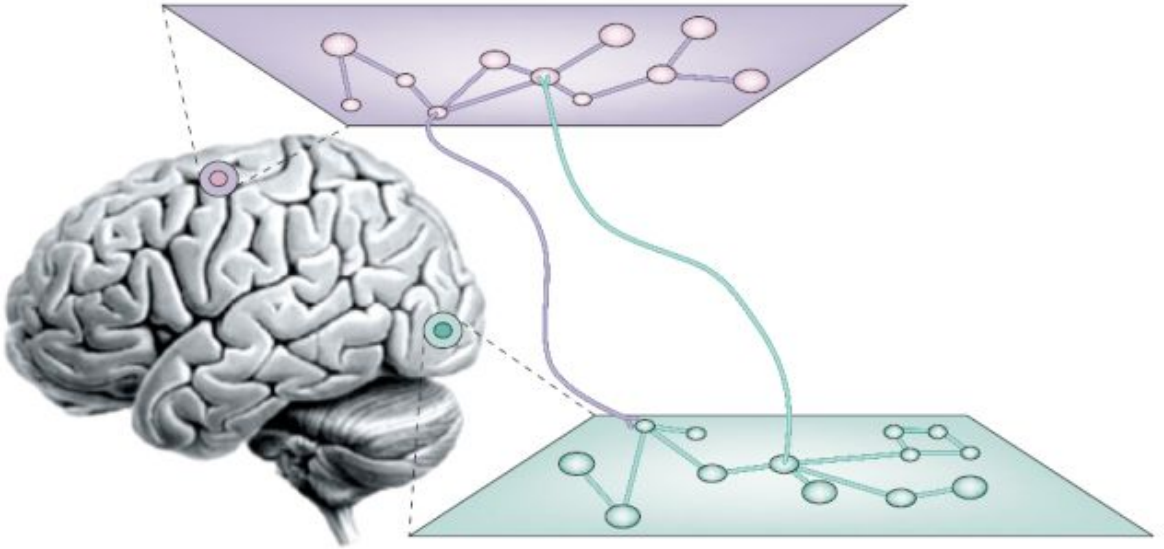
NeuroHackAdemy 2019

Why parcellations? Understand brain organization

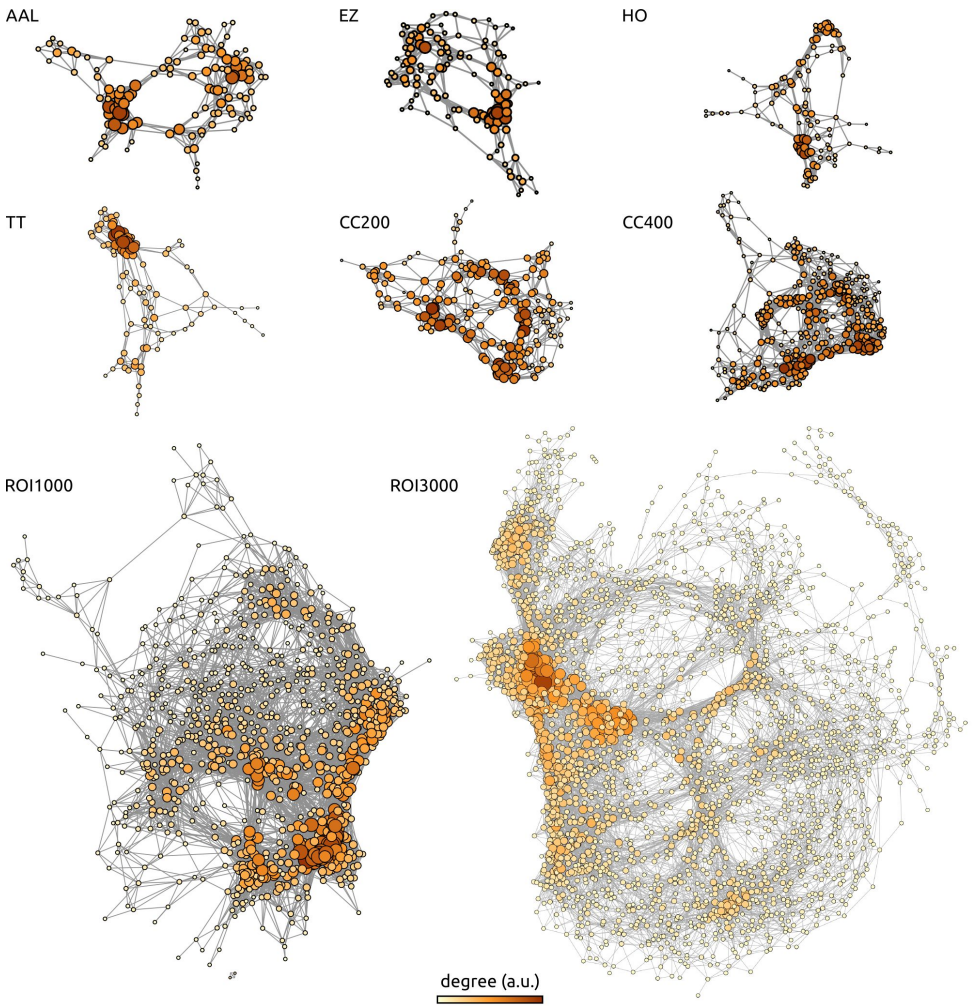


Local and distributed connectivity lead to the emergence of both local and distributed neuronal assemblies. From Varela et al., 2001.

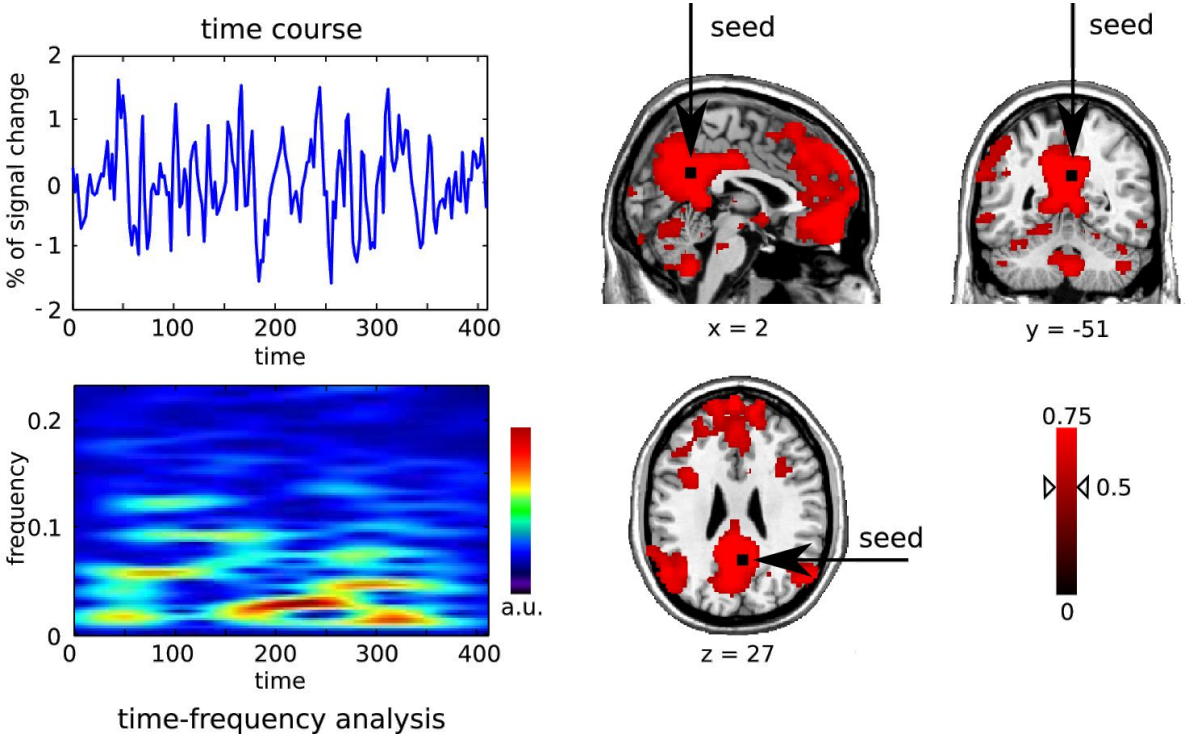
Why parcellations? Reduce dimension

Parcels can be used as nodes to approximate brain networks as graphs. Here, the average connectome of the ADHD-200 sample is represented with several different parcellations, of varying resolutions.

From Bellec et al., Neuroimage 2017.

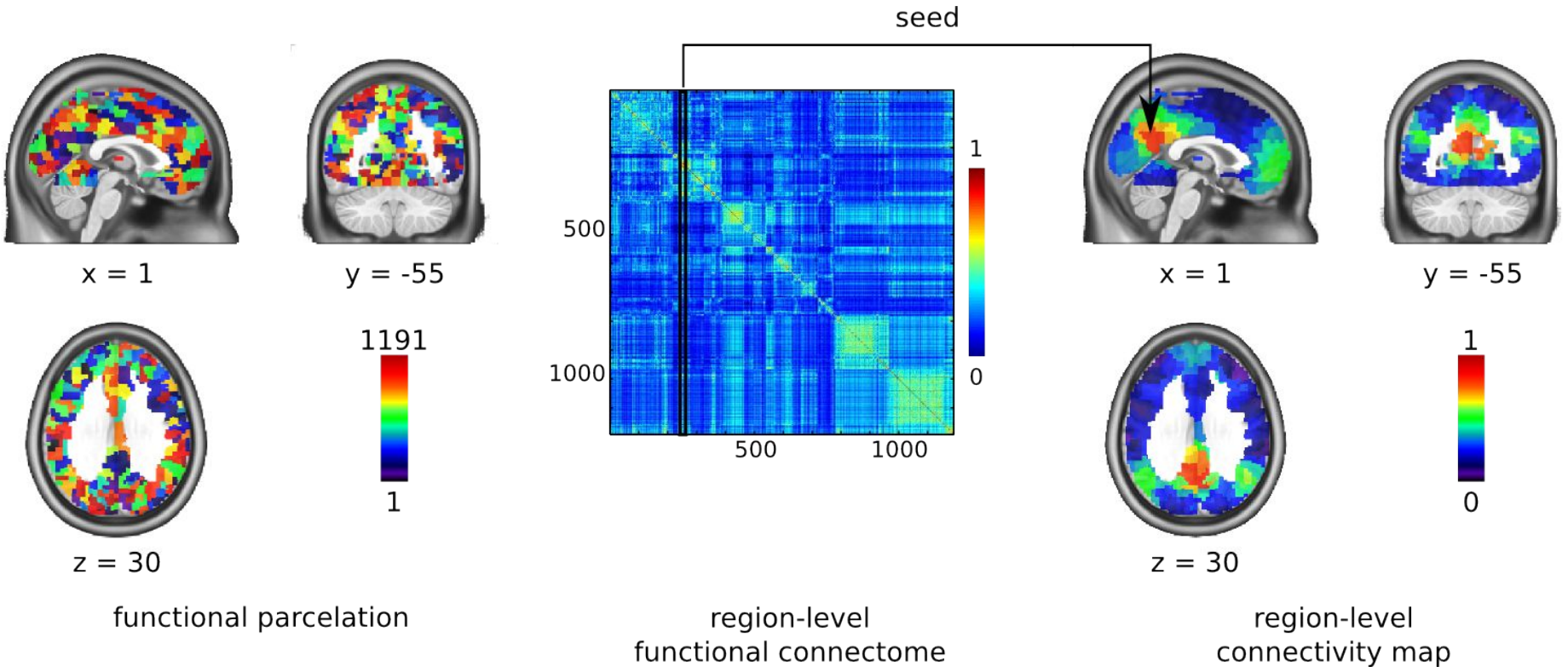


Functional connectivity map



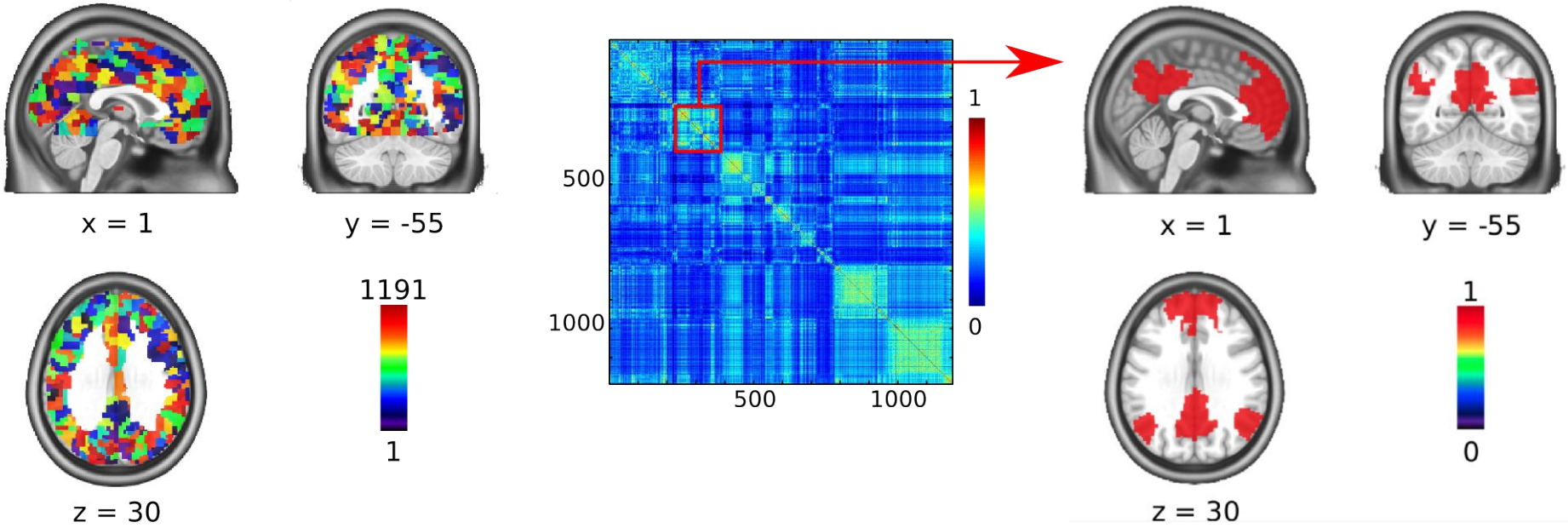
Slow spontaneous fluctuations and seed-based connectivity map from the posterior cingulate cortex identifies the default-mode network.

Functional connectome



A functional connectome essentially is a collection of seed-based connectivity maps, approximated on parcels, and using all possible seeds.

Functional networks



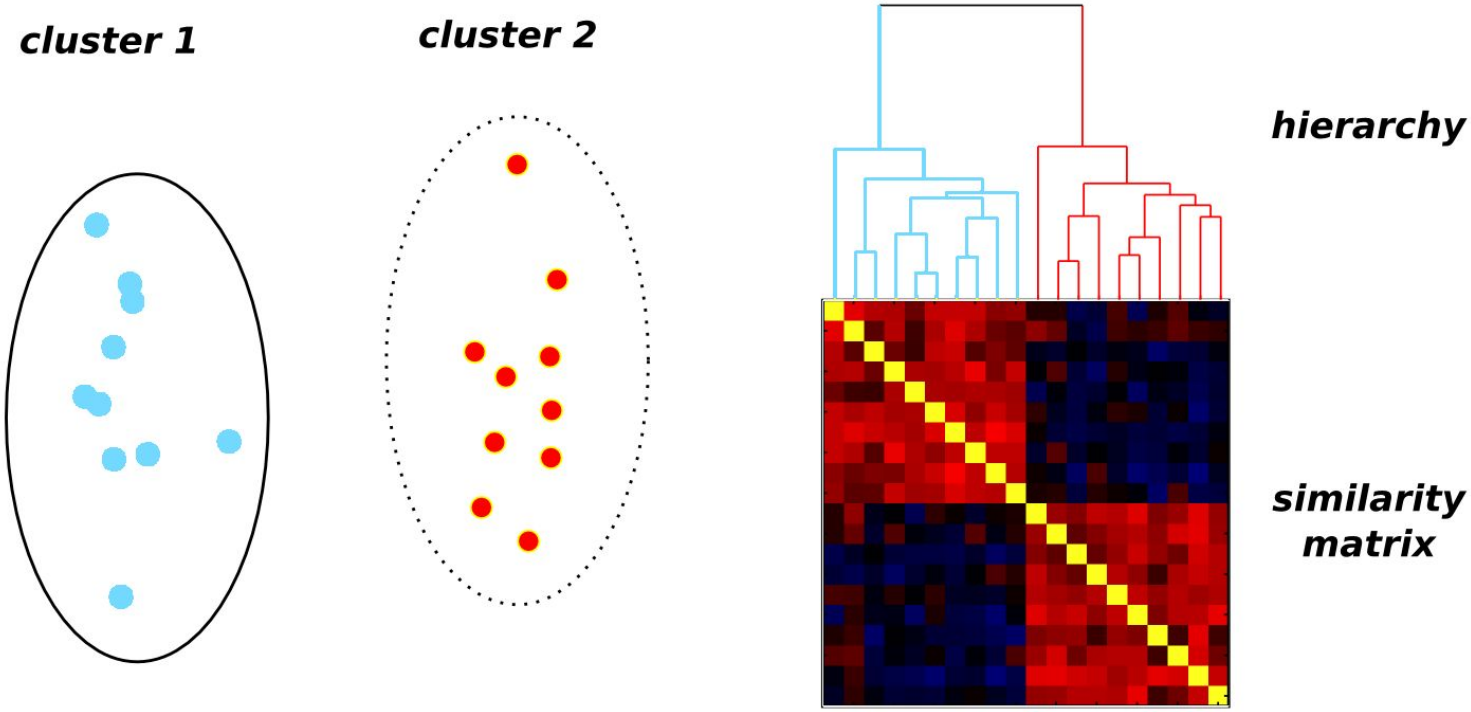
functional parcelation

region-level
functional connectome

resting-state
network

If we order the parcels correctly, we can see functional networks as diagonal squares with high connectivity on the diagonal.

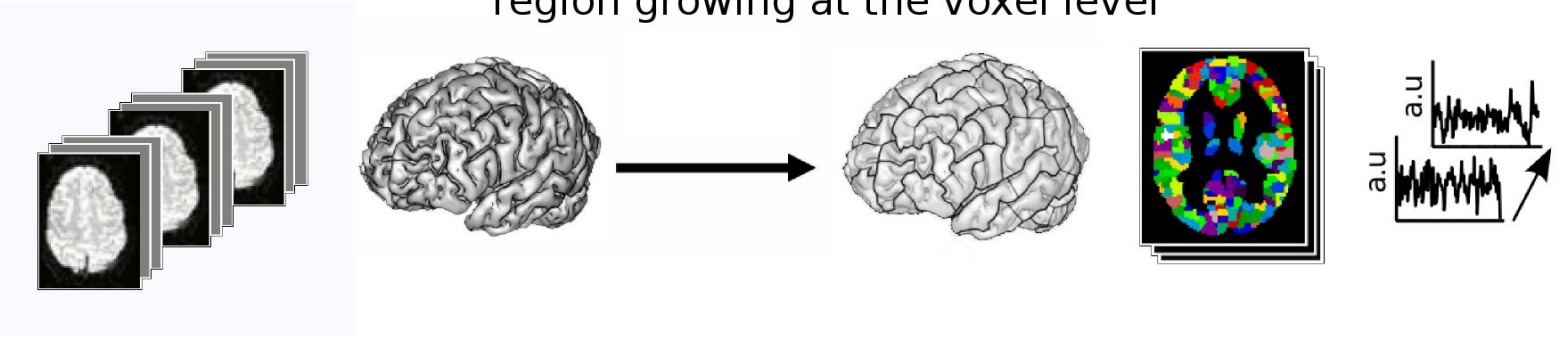
General purpose cluster analysis



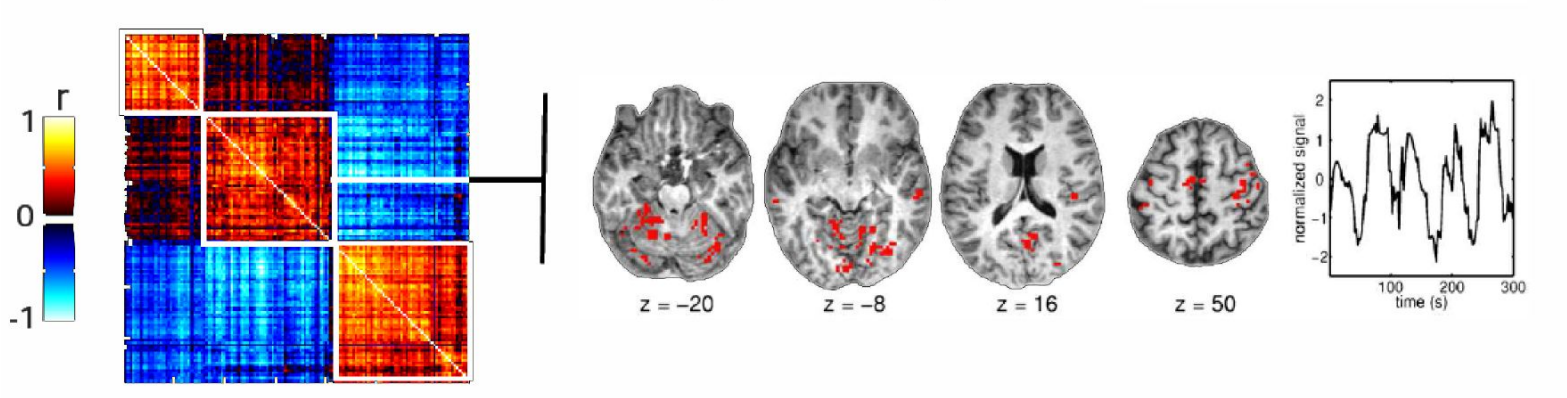
On the left, coordinates of individuals define their similarities; on the right, agglomerative hierarchical clustering proceeds by iterative mergings. Many clustering algorithms exist, e.g. k-means, fuzzy k-means, spectral clustering, SOM, neural gas. See Jain, Pattern Recognition Letters, 2009, for a review of classic approaches.

Brain cluster analysis

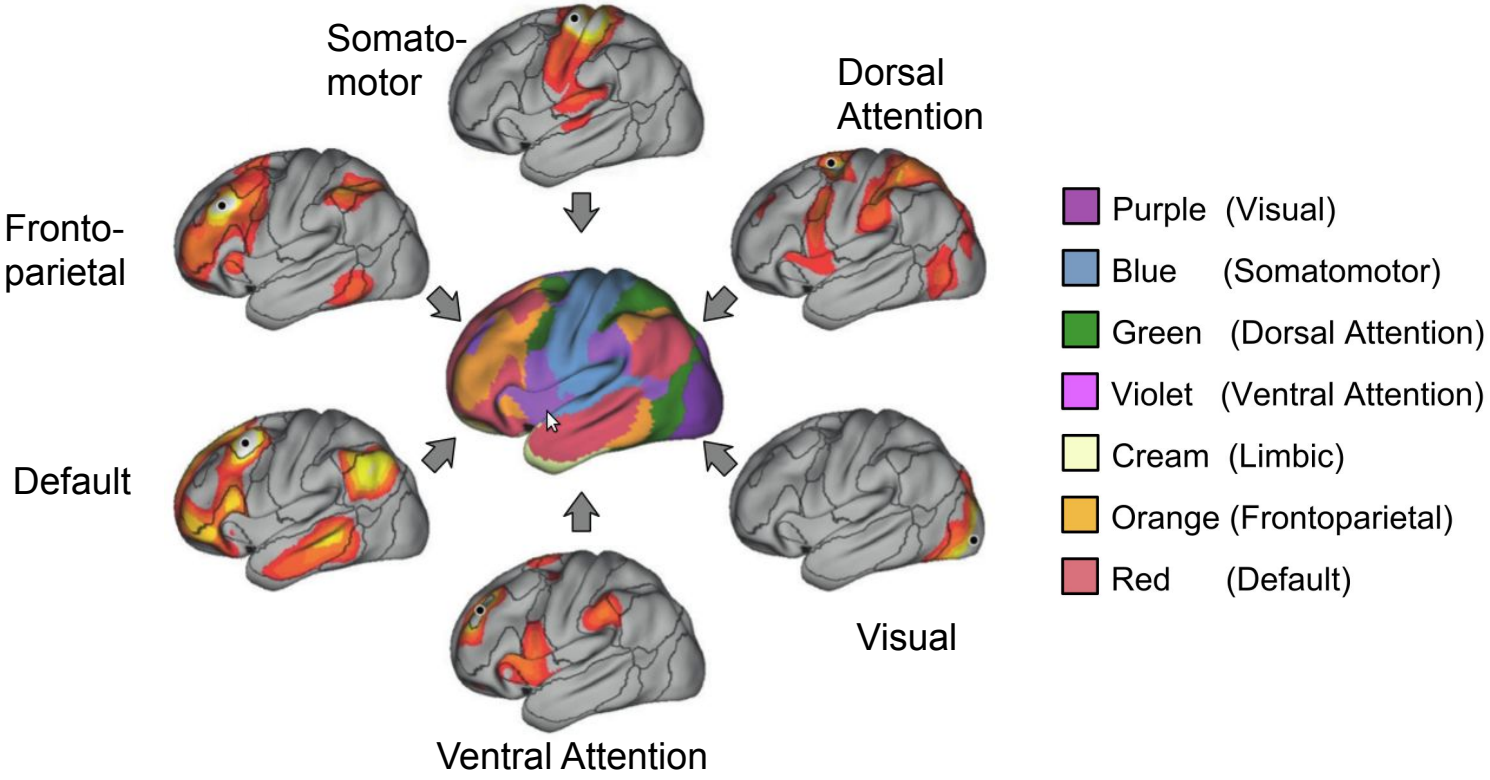
region growing at the voxel level



clustering at the region level

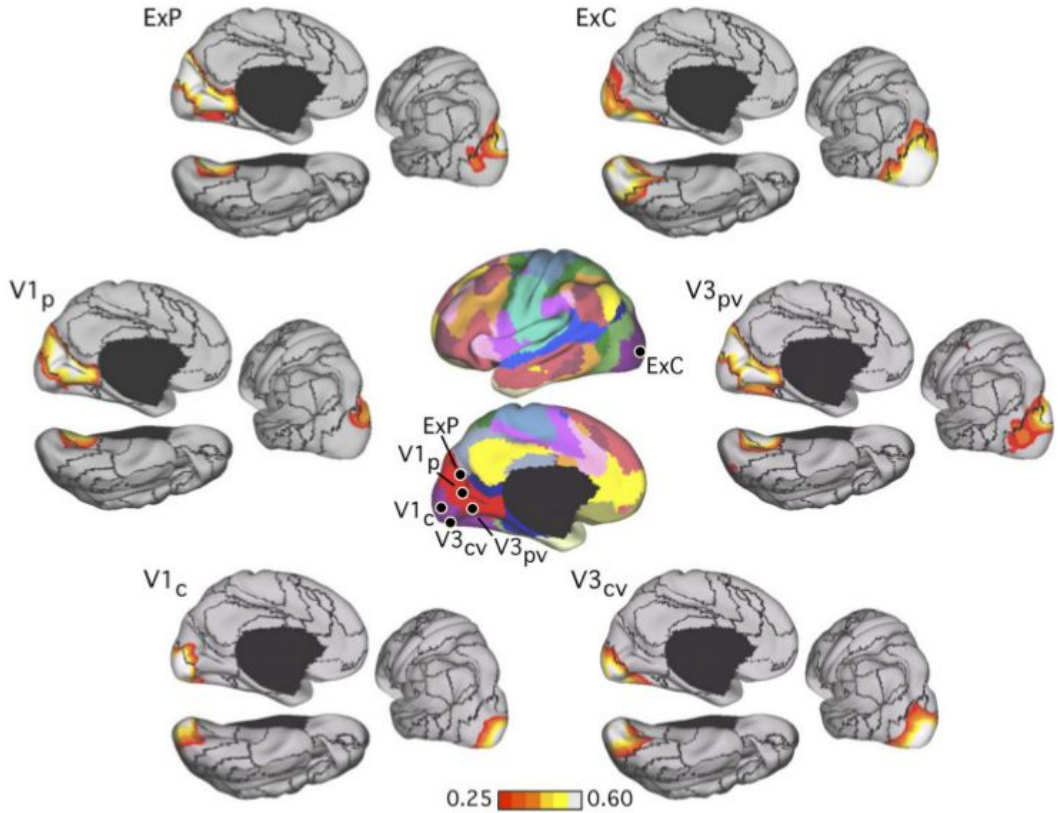


Yeo-Krienen-7-clusters



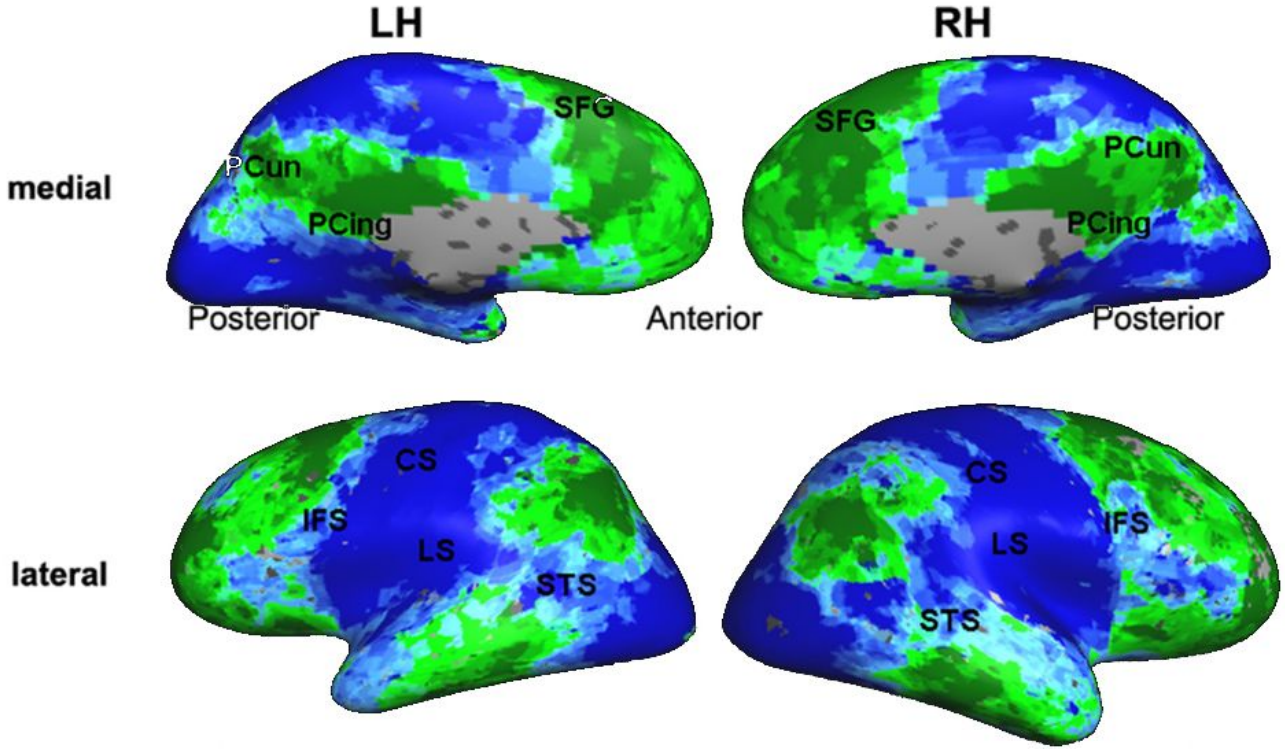
Decomposition of the brain into 7 group networks by Yeo, Krienen et al (2011).

Yeo-Krienen-17-clusters (visual)



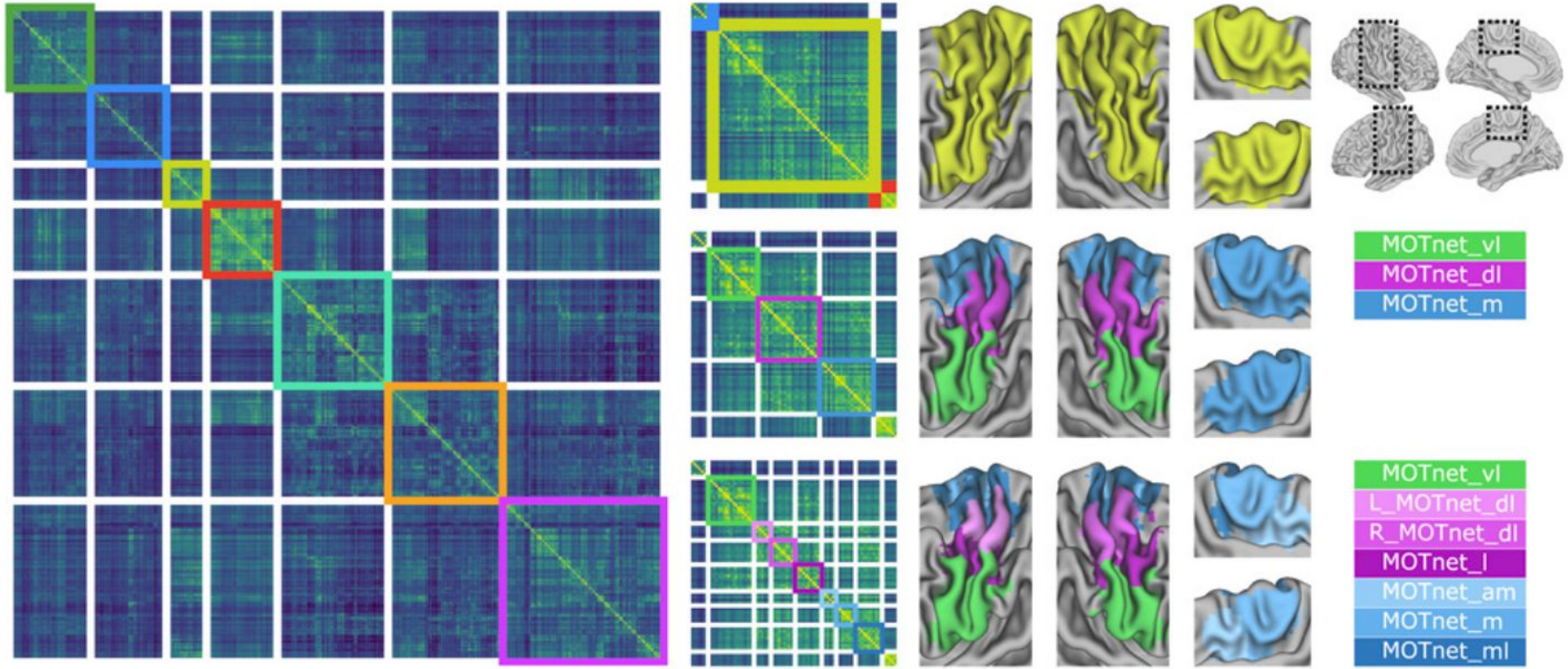
Networks can be further divided into subnetworks, here in the visual cortex. From Yeo, Krienen et al. (2011).

Golland-2-clusters



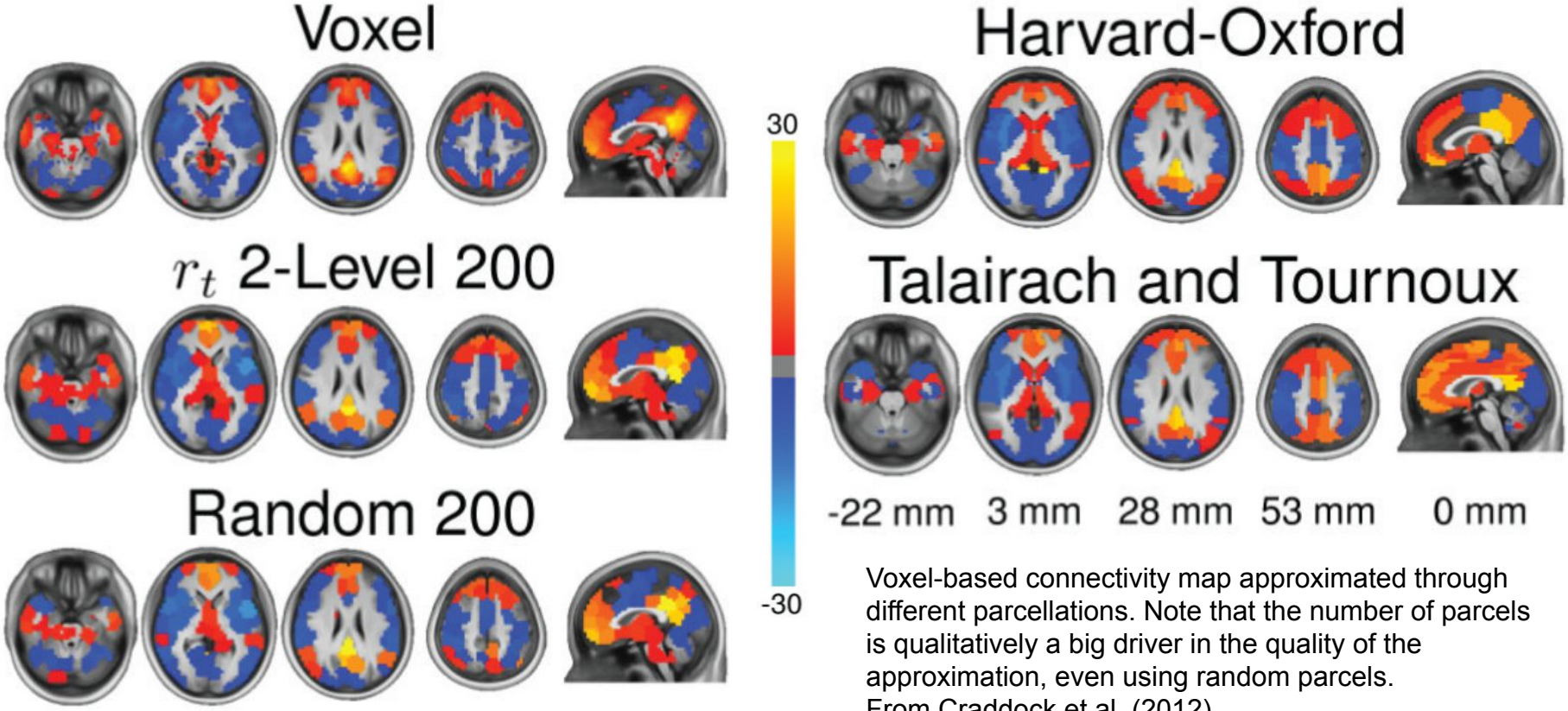
Note that Networks can also be merged into reliable “exogeneous” vs “endogeneous” systems. From Golland et al. (2008).

What is the number of clusters?



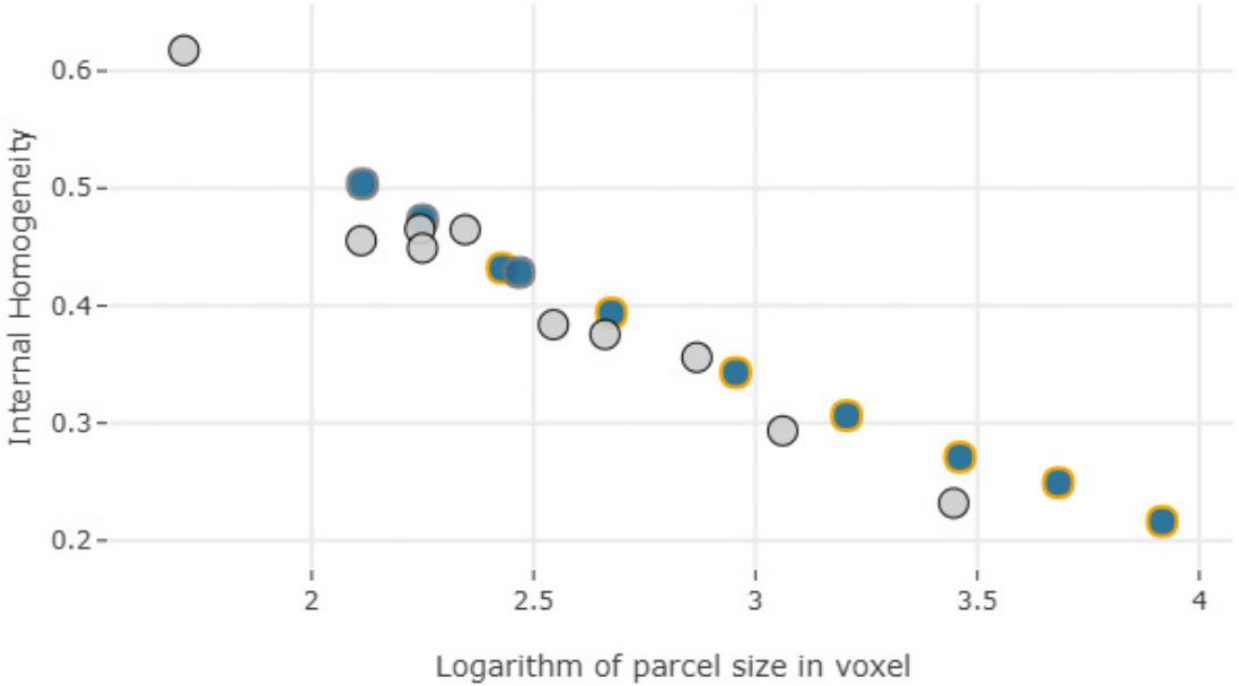
Functional brain parcels break down into a pseudo-hierarchy, here illustrated in the sensorimotor network. There thus exists multiple numbers of acceptable decomposition in brain parcels. From Urchs et al, MNI open research (2017).

How homogeneous are parcels?



Voxel-based connectivity map approximated through different parcellations. Note that the number of parcels is qualitatively a big driver in the quality of the approximation, even using random parcels.
From Craddock et al. (2012).

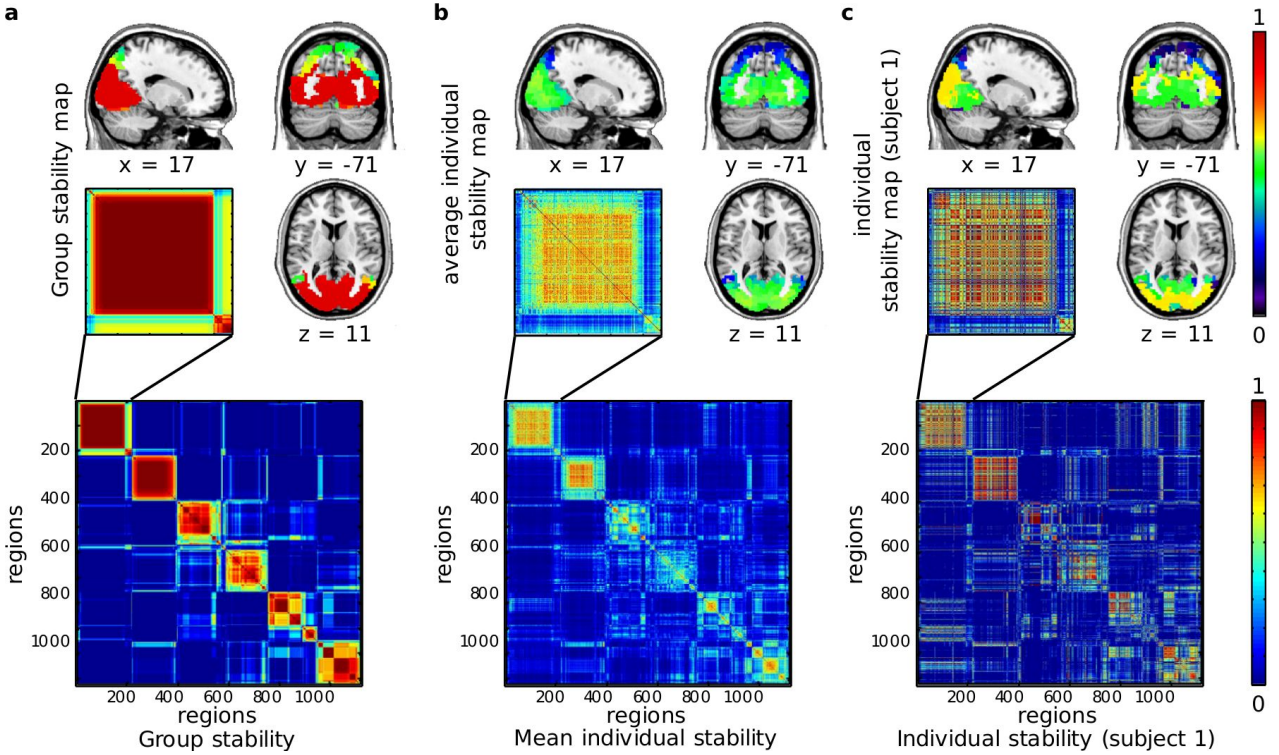
How homogeneous are parcels?



Homogeneity of group brain parcels as a function of the average parcel size for a series of multiresolution functional parcels (MIST) as well other published parcellations (Yeo-Krienen-7, Yeo-Krienen-17, OasisTRT, AAL, Aicha, Brainnetome, Hammersmith, Shen, Gordon, Glasser). Note that homogeneity can closely be predicted from size alone. From Urchs et al. MNI open research (2017).

How stable are parcels?

Stability matrices represent the probability of any given pair of super-voxel to be in the same cluster, either at the group (a), average individual (b), and individual (c), through replications of the clustering process. Group parcels are already quite stable with a moderate number of individuals (N=43), while individual parcels are quite contrasted, with a few stable networks and several areas of low stability (15 mns of resting-state fMRI). These areas are not consistent across subject, leading to moderate average individual stability. From Bellec et al. (2010).



What is a good parcellation?

A number of metrics are emerging as standard benchmarks for parcellation:

- Homogeneity
- Stability
- Agreement with task activation (shown here on the left).
- Overlap with cytoarchitecture and myelination gradient.

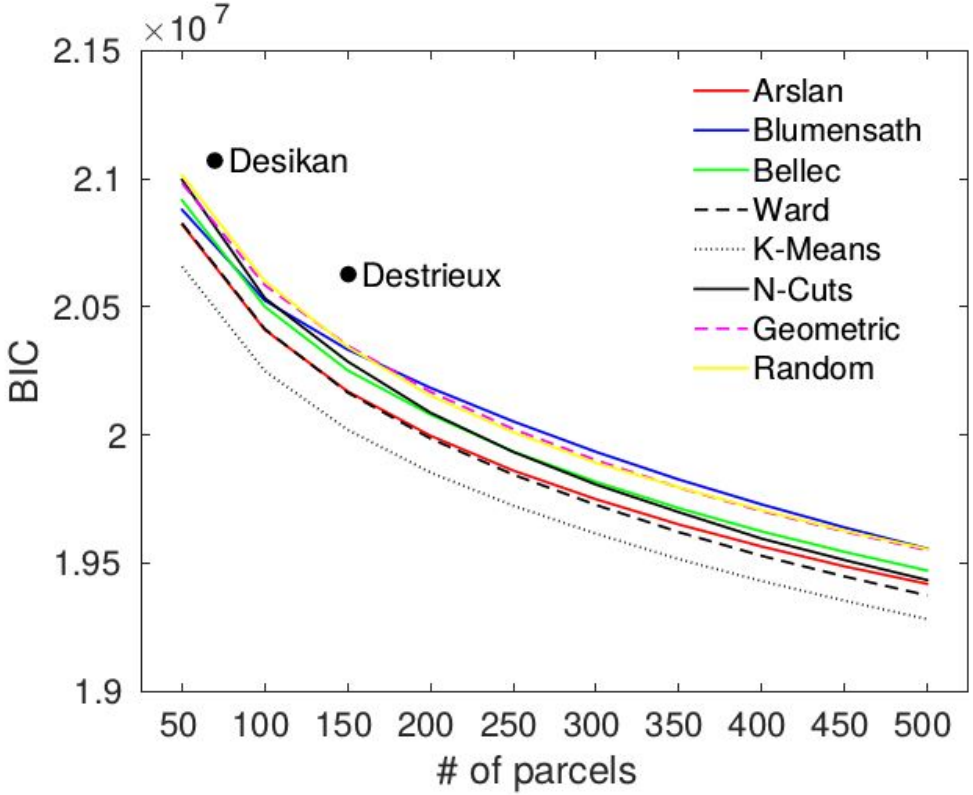
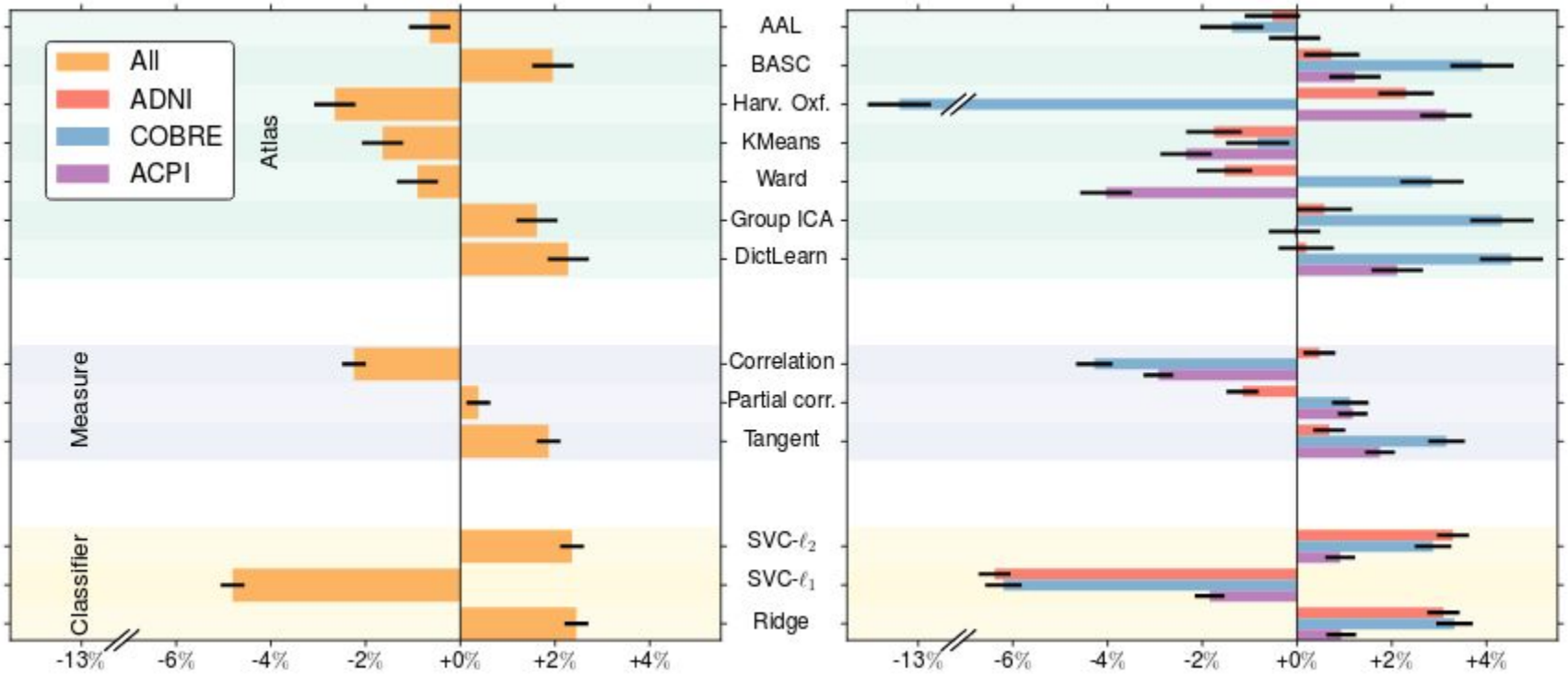


Figure and benchmarks from Arslan et al. Neuroimage 2017 (HCP data).

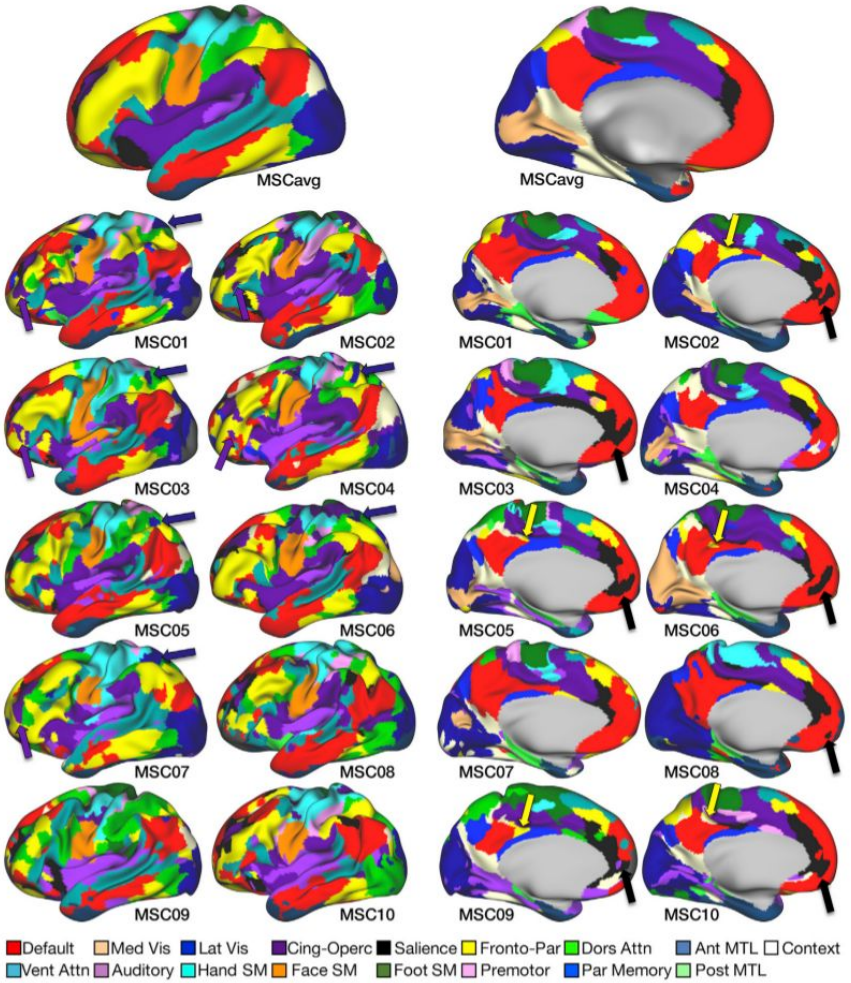
What is a good parcellation?



Comparison of the impact of different methodological choices on the accuracy of different classification tasks (ADNI, COBRE, ACPI). AAL and “legacy” (Kmeans, Ward) techniques perform poorly, while functional parcels (BASC, Group ICA, DictLearn) have good performance, and Harv Oxf has uneven performances. From Dadi et al., PRNI 2016.

How to go from group to individual parcels?

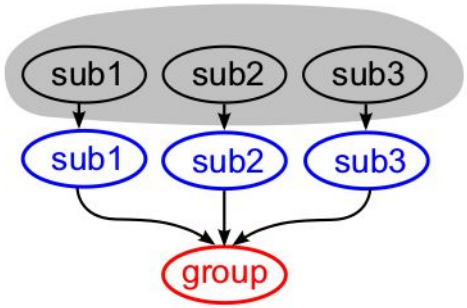
For ten densely sampled individuals (10 runs of 30 mns resting-state over ten days) identify details in individual parcellations that cannot be observed at the level of group parcellations (indicated by arrows, group parcellation at the top).



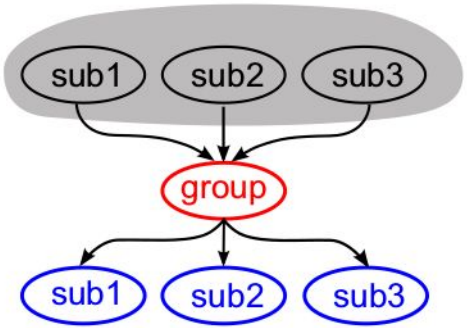
How to go from group to individual parcels?

fMRI
time courses

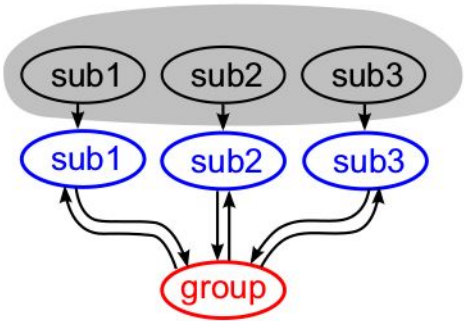
functional
network map



[Bellec, 2010]
[Van Den Heuvel, 2008]
[Esposito, 2005]



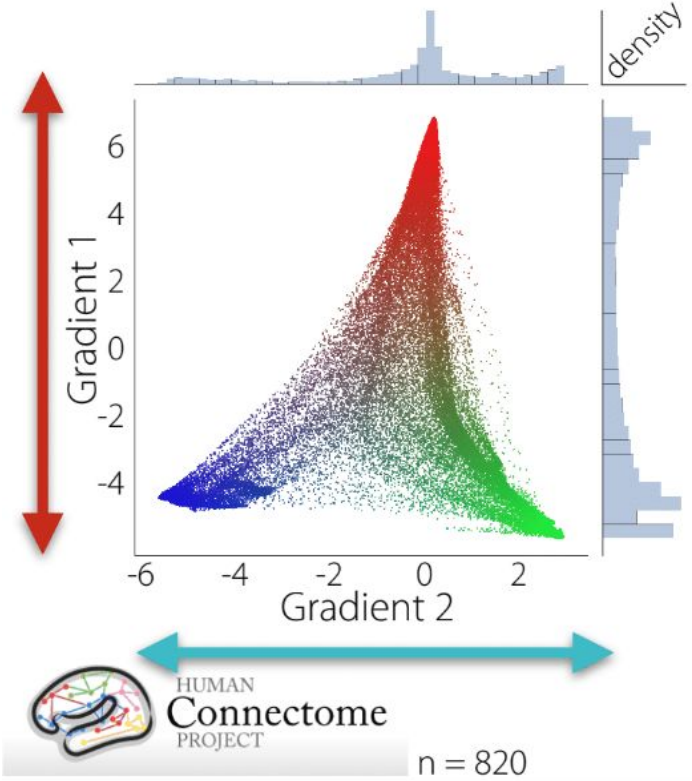
[Calhoun, 2001b]
[Beckmann, 2009]
[Filippini, 2009]

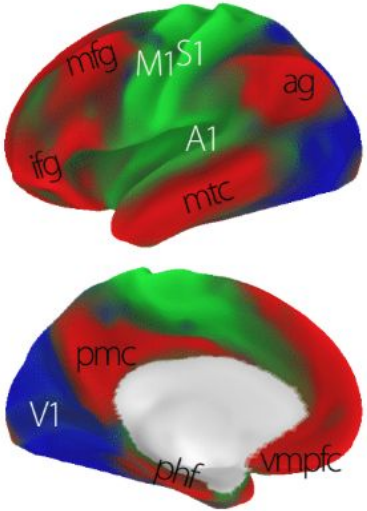


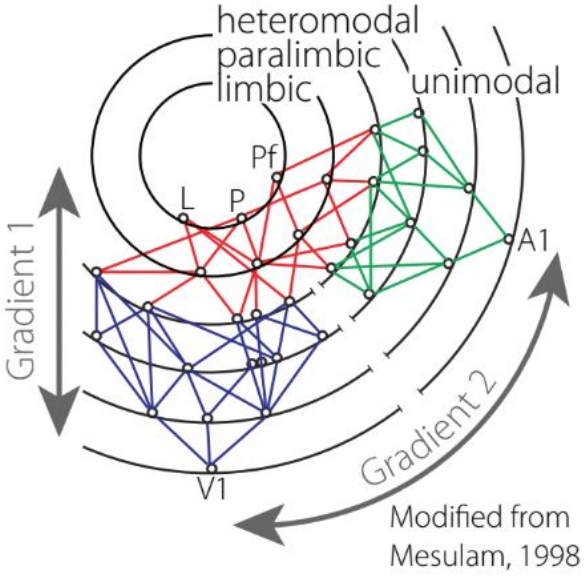
[Varoquaux, 2010, 2011]
[Ng, 2010]
[Liu, 2014]
[Salehi et al., 2018]
[Kong et al., 2018]

Adapted from Liu et al., Neuroimage 2014.

Parcels or gradients?



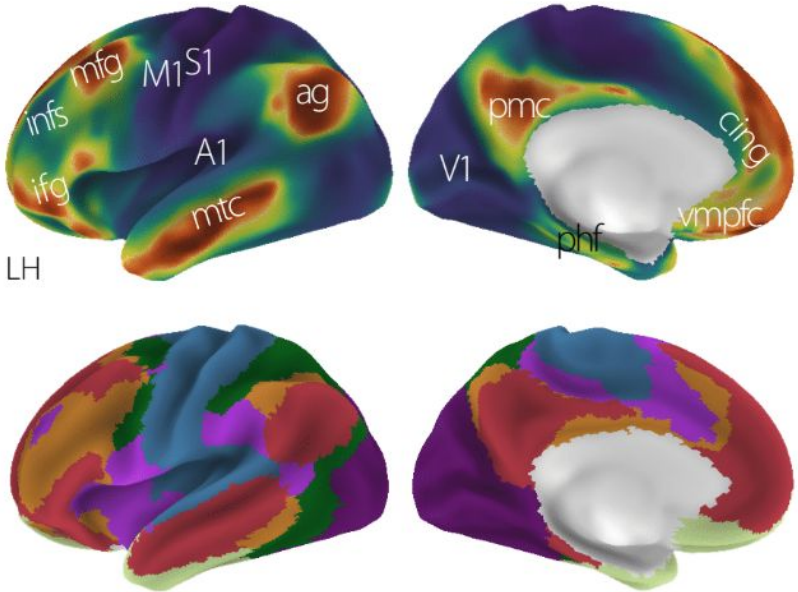


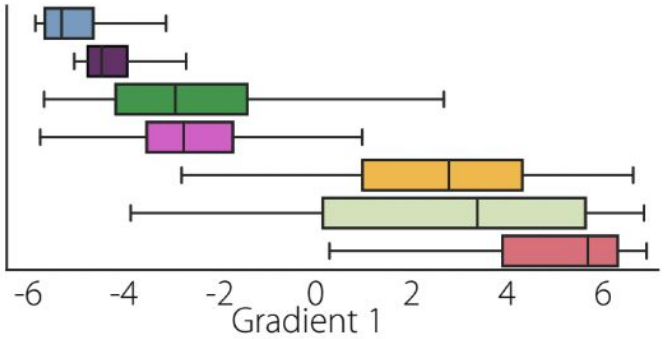


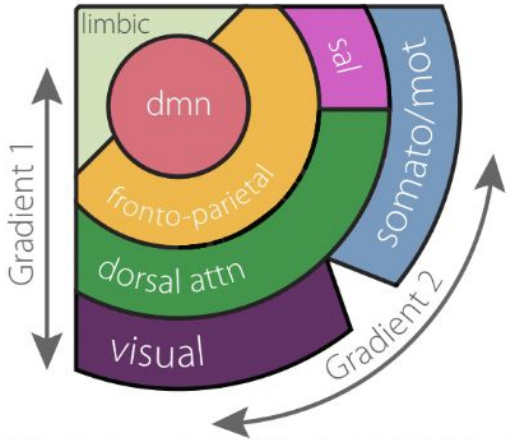
Spectral embedding applied on the brain graph Laplacian identifies multiple continuous gradients of connectivity.

Margulies et al, *PNAS, 2016*

Parcels or gradients?







The first gradient orders sequentially the main networks from the Yeo-Krienen-7-clusters parcellation.
From Margulies et al., PNAS 2016.

Summary

- Functional parcelations are modules of brain regions with higher homogeneity intra-module than inter-modules.
- Parcelations exist over a range of scales, from distributed network down to specialized cortical areas.
- Homogeneity increases with scale.
- Stability is high at group-level, uneven at individual-level.
- A number of benchmarks are now established to compare parcellation algorithms.
- There are substantial differences between individual and group parcellations, and these two levels can be estimated jointly.
- Gradients (or any linear mixture) provide a complementary, richer view on brain organization than parcels, but are also more complex.