HEINRICH HEINE UNIVERSITÄT DÜSSELDORF
SYSTEMS NEUROSCIENCE

JÜLICH FORSCHUNGSZENTRUM

Co-activation mapping and Parcellation

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Meta-Analyses

- **Topic based meta-analyses:**

  derive brain regions consistently found across studies investigating a specific function

- **Location based meta-analyses:**

Meta-Analyses

- **Topic based meta-analyses:**

  derive brain regions consistently found across studies investigating a specific function

Meta-Analyses

- **Topic based meta-analyses:**

  derive brain regions consistently found across studies investigating a specific function

- **Location based meta-analyses:**

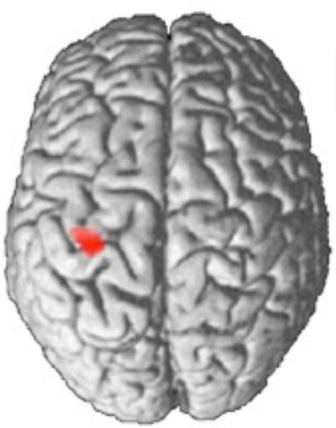
  derive brain regions consistely found to activate together with a specific region across studies investigating different functions

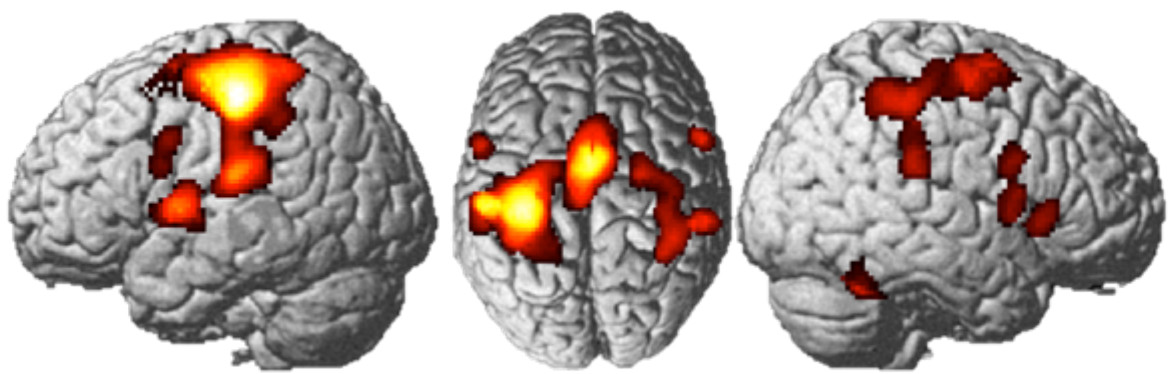
Meta-Analyses

- **Topic based meta-analyses:**

  derive brain regions consistently found across studies investigating a specific function

- **Location based meta-analyses:**

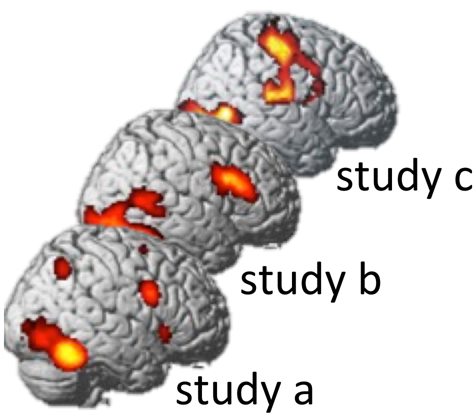


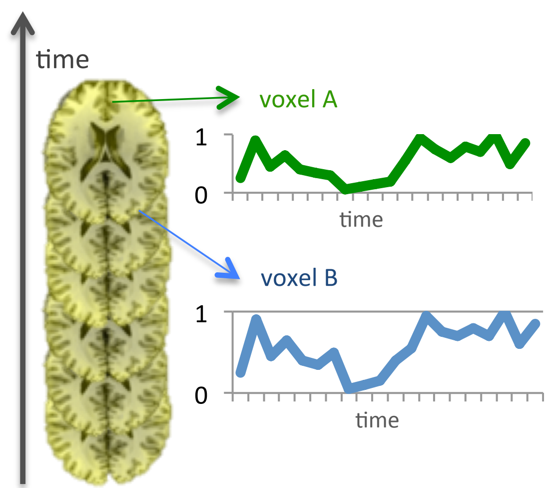


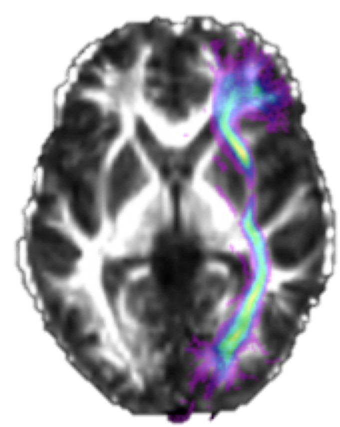
„ left M1 functional network „

MRI/PET-based connectivity

	Functional: Functional MRI & PET		Structural/anatomical: Diffusion MRI
Data	Task-based fMRI & PET (behavioral task !)	Resting state fMRI (no behavioral task !)	Diffusion MRI
Concept	Task-based: Activation during task	Resting-state: Signal fluctuations at rest	Diffusion-based: Estimation of fiber direction
How ?	E.g.: Meta-Analytic Connectivity Modeling (MACM)	Correlation in signal fluctuations	E.g. : probabilistic diffusion tractography







Functional Connectivity

- **Functional Connectivity:**
  - Temporal coincidence of spatially distinct neurophysiological events
  - Task-based fMRI: Concurrent activity of brain regions

    → Co-activation

- **Location based meta-analyses:**
  - Co-activations consistently found across different experiments
  - Meta-analysis as a tool to derive functional connectivity

    → Meta-analytical connectivity modeling (MACM)

Databases

http://brainmap.org/

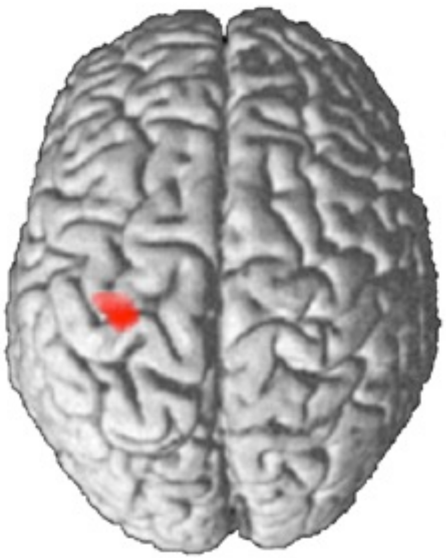
3139 papers
15549 experiments
121082 locations

- Coordinates in stereotactic space
- Experimental information

MACM : Workflow

- Identification of all experiments activating the seed region
- General and specific inclusion/exclusion criteria
- Extraction of all coordinates reported in identified experiments
- Performing a meta-analysis across identified experiments

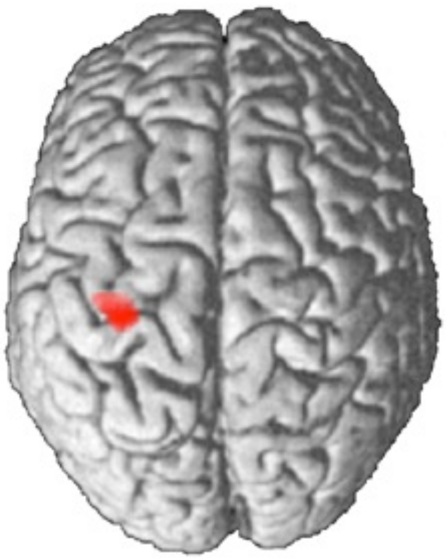
Co-activation of left M1



Which brain regions are functionally connected to left M1 ?

Co-activation of left M1

- Identify all experiments activating the seed region

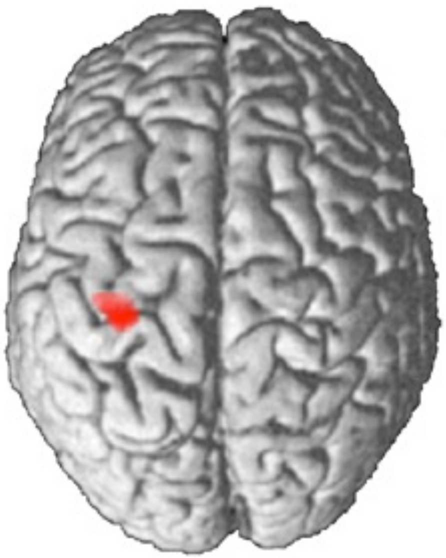


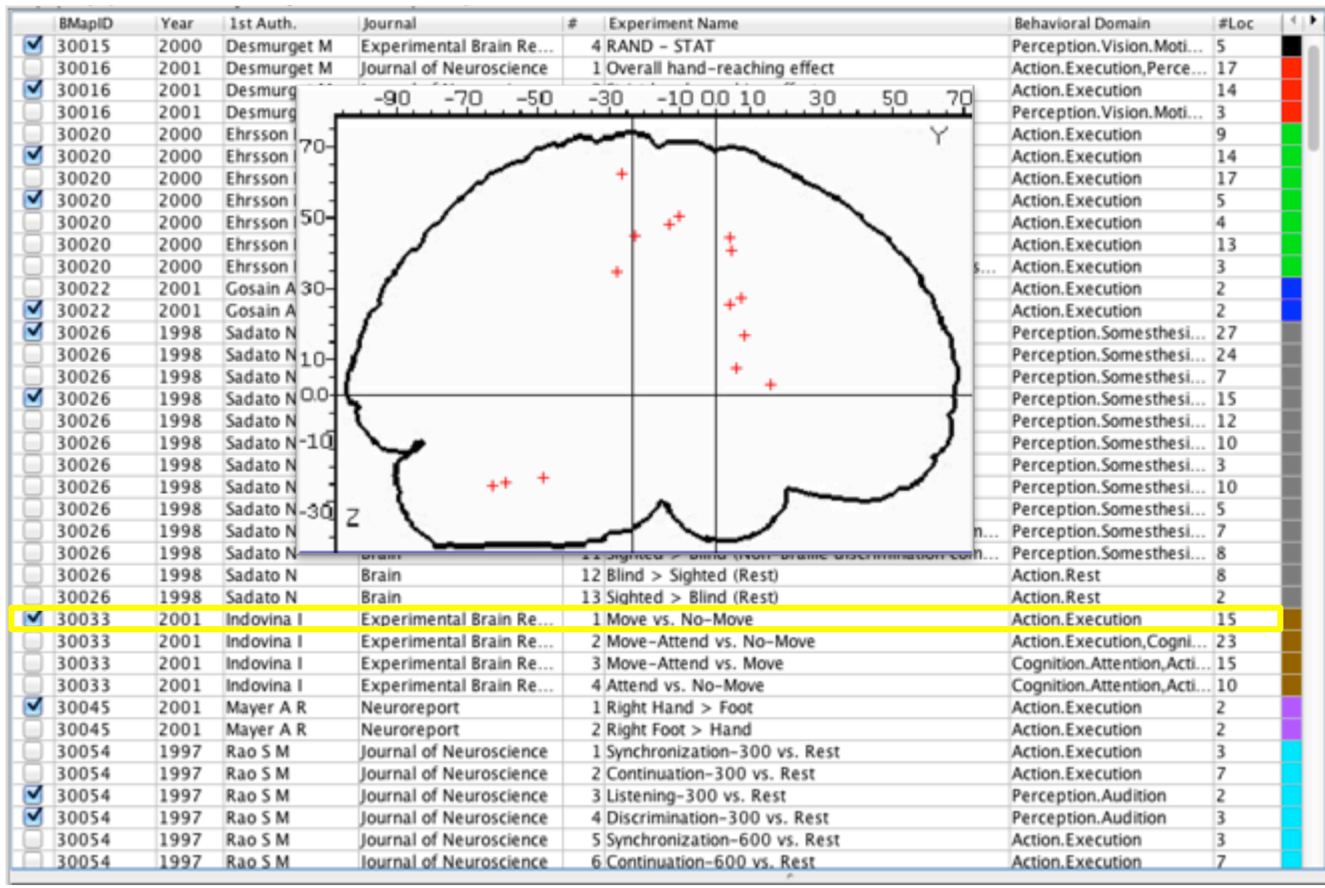
155 experiments activating left M1

	BMapID	Year	1st Auth.	Journal	#	Experiment Name	Behavioral Domain	#Loc
✓	30015	2000	Desmurget M	Experimental Brain Re...	4	RAND - STAT	Perception.Vision.Moti...	5
	30016	2001	Desmurget M	Journal of Neuroscience	1	Overall hand-reaching effect	Action.Execution,Perce...	17
✓	30016	2001	Desmurget M	Journal of Neuroscience	2	Strict hand-reaching effect	Action.Execution	14
	30016	2001	Desmurget M	Journal of Neuroscience	3	Eye error correction effect	Perception.Vision.Moti...	3
	30020	2000	Ehrsson H H	European Journal of N...	1	Foot vs. Rest	Action.Execution	9
✓	30020	2000	Ehrsson H H	European Journal of N...	2	Hand vs. Rest	Action.Execution	14
	30020	2000	Ehrsson H H	European Journal of N...	3	Simultaneous vs. Rest	Action.Execution	17
✓	30020	2000	Ehrsson H H	European Journal of N...	4	Hand vs. Foot	Action.Execution	5
	30020	2000	Ehrsson H H	European Journal of N...	5	Foot vs. Hand	Action.Execution	4
	30020	2000	Ehrsson H H	European Journal of N...	6	Conjunction Analysis	Action.Execution	13
	30020	2000	Ehrsson H H	European Journal of N...	7	((Hand - Rest) + (Foot - Rest)) - (Simultaneous...	Action.Execution	3
	30022	2001	Gosain A K	Plastic and Reconstruct...	1	Smile vs. Rest	Action.Execution	2
✓	30022	2001	Gosain A K	Plastic and Reconstruct...	2	Finger-tapping vs. Rest	Action.Execution	2
✓	300							
	300							
	300							
✓	300							
	300							
	30026	1998	Sadato N	Brain	6	Discrimination-Sweep (Sighted)	Perception.Somesthesi...	10
	30026	1998	Sadato N	Brain	7	Sweep-Rest (Blind)	Perception.Somesthesi...	3
	30026	1998	Sadato N	Brain	8	Discrimination-Rest (Blind)	Perception.Somesthesi...	10
	30026	1998	Sadato N	Brain	9	Rest-Discrimination (Blind)	Perception.Somesthesi...	5
	30026	1998	Sadato N	Brain	10	Blind > Sighted (Non-Braille discrimination com...	Perception.Somesthesi...	7
	30026	1998	Sadato N	Brain	11	Sighted > Blind (Non-Braille discrimination com...	Perception.Somesthesi...	8
	30026	1998	Sadato N	Brain	12	Blind > Sighted (Rest)	Action.Rest	8
	30026	1998	Sadato N	Brain	13	Sighted > Blind (Rest)	Action.Rest	2
✓	30033	2001	Indovina I	Experimental Brain Re...	1	Move vs. No-Move	Action.Execution	15
	30033	2001	Indovina I	Experimental Brain Re...	2	Move-Attend vs. No-Move	Action.Execution,Cogni...	23
	30033	2001	Indovina I	Experimental Brain Re...	3	Move-Attend vs. Move	Cognition.Attention,Acti...	15
	30033	2001	Indovina I	Experimental Brain Re...	4	Attend vs. No-Move	Cognition.Attention,Acti...	10
✓	30045	2001	Mayer A R	Neuroreport	1	Right Hand > Foot	Action.Execution	2
	30045	2001	Mayer A R	Neuroreport	2	Right Foot > Hand	Action.Execution	2
	30054	1997	Rao S M	Journal of Neuroscience	1	Synchronization-300 vs. Rest	Action.Execution	3
	30054	1997	Rao S M	Journal of Neuroscience	2	Continuation-300 vs. Rest	Action.Execution	7
✓	30054	1997	Rao S M	Journal of Neuroscience	3	Listening-300 vs. Rest	Perception.Audition	2
✓	30054	1997	Rao S M	Journal of Neuroscience	4	Discrimination-300 vs. Rest	Perception.Audition	3
	30054	1997	Rao S M	Journal of Neuroscience	5	Synchronization-600 vs. Rest	Action.Execution	3
	30054	1997	Rao S M	Journal of Neuroscience	6	Continuation-600 vs. Rest	Action.Execution	7

Co-activation of left M1

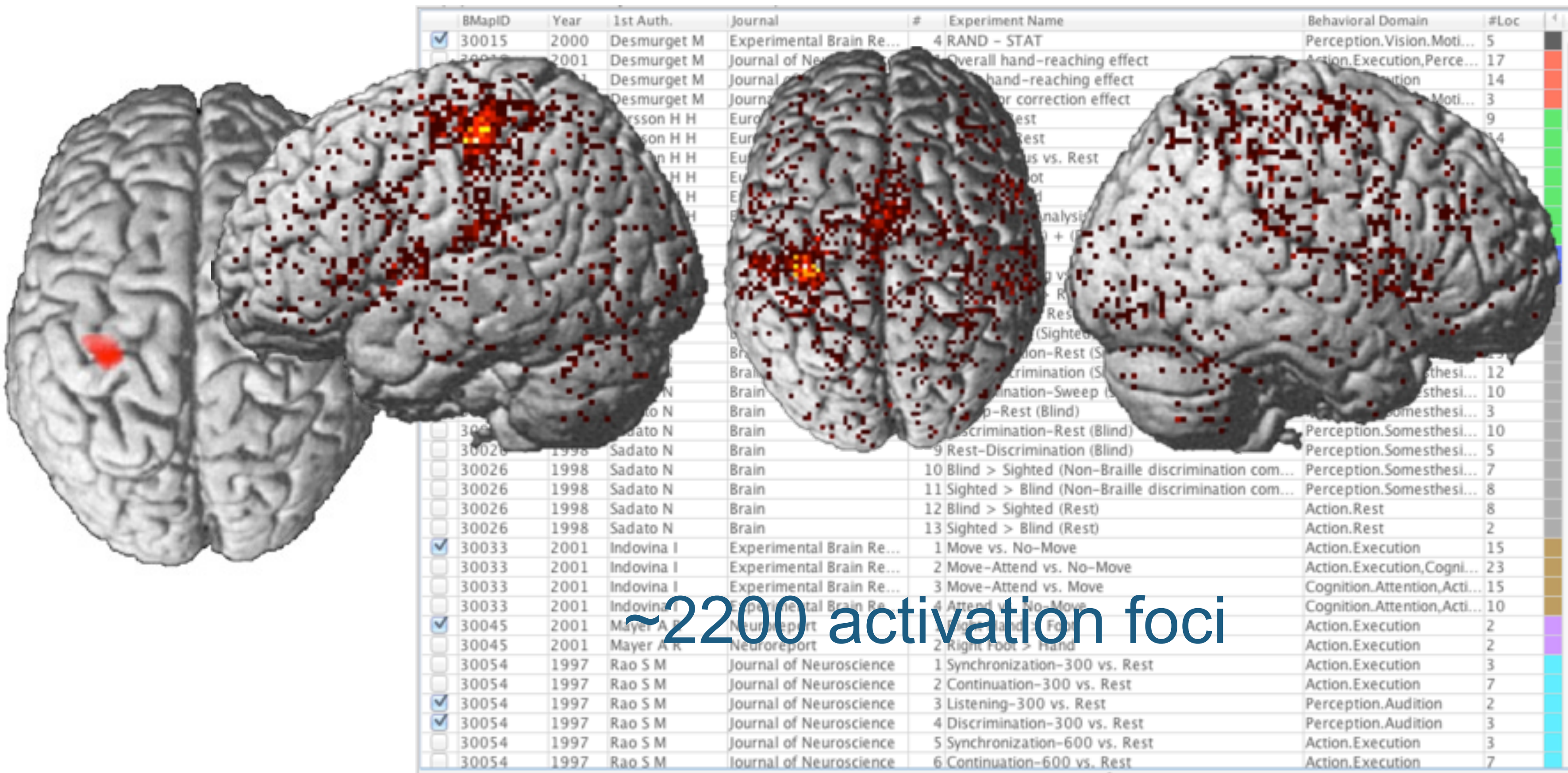
- Extract all coordinates





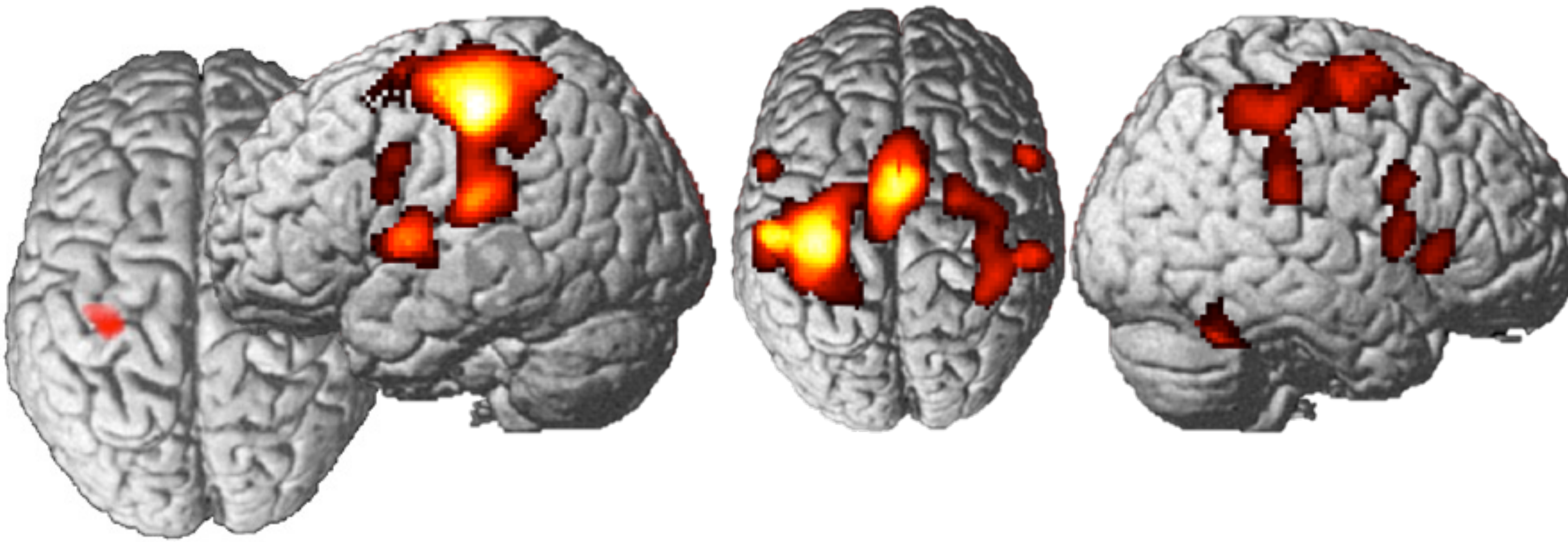
Co-activation of left M1

- Extract all coordinates from 155 experiments



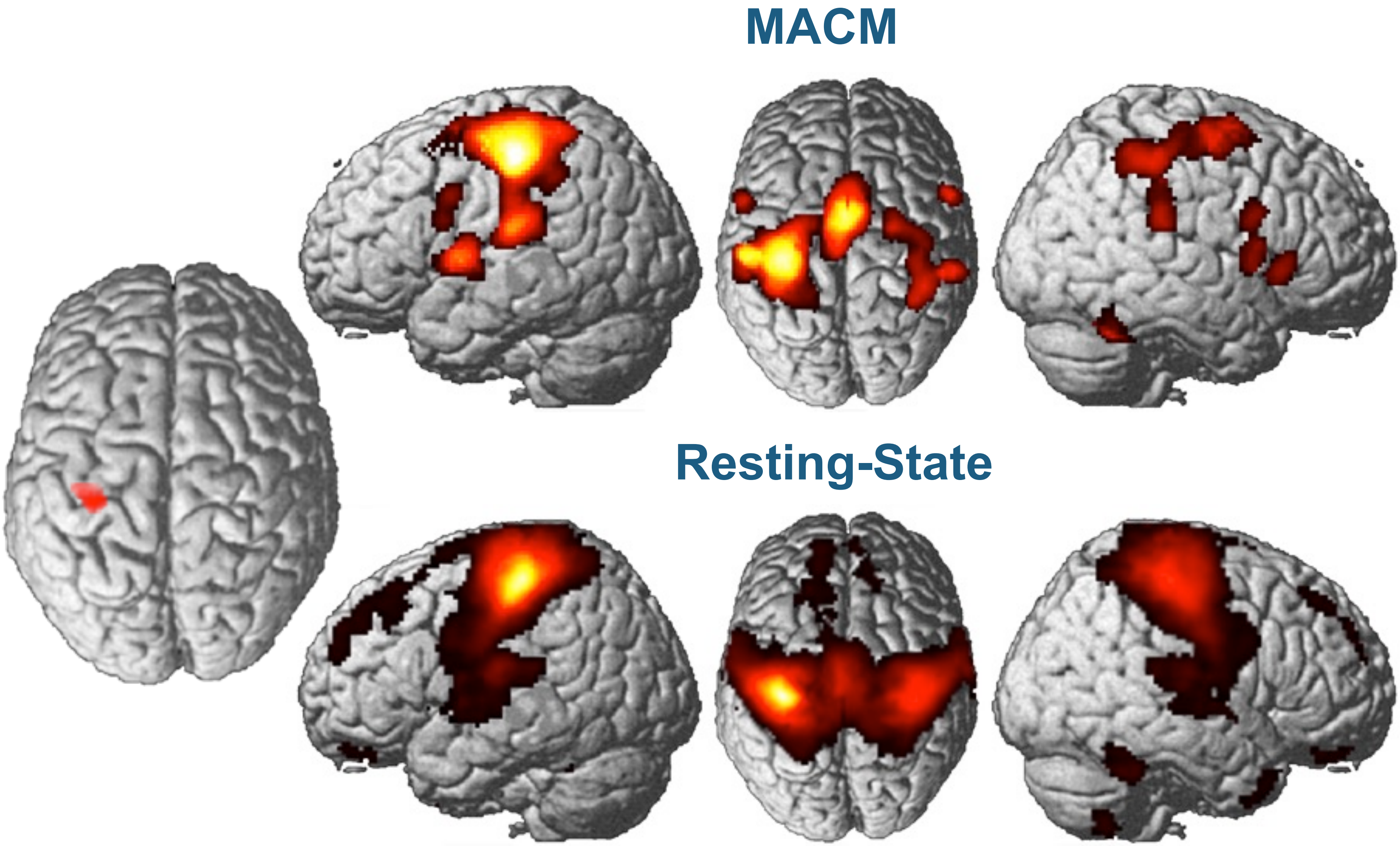
Co-activation of left M1

- Perform a meta-analysis across identified experiments



Network significantly co-activating with M1

Comparison to resting state functional connectivity



Functional Connectivity

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- **Location based meta-analyses:**
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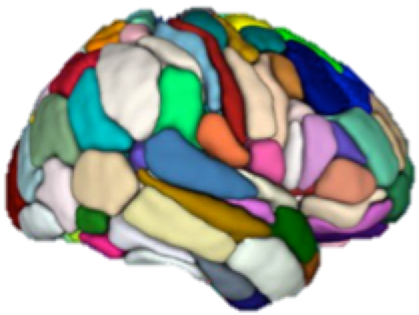
    - → Meta-analytical connectivity modeling (MACM)

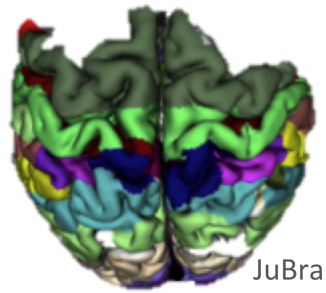
➔ **Functional connectivity to parcellate the brain**

Brain parcellation

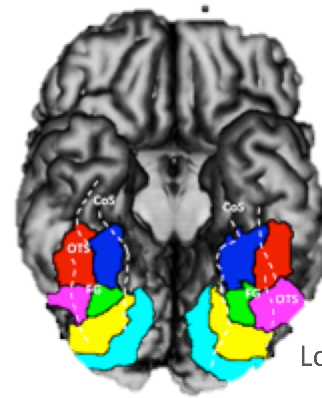
- **The brain is topographically organized**



Fan et al., 2016



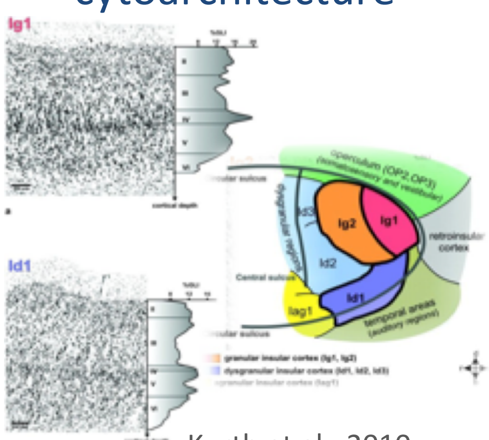
JuBrain



Lorenz et al., 2017

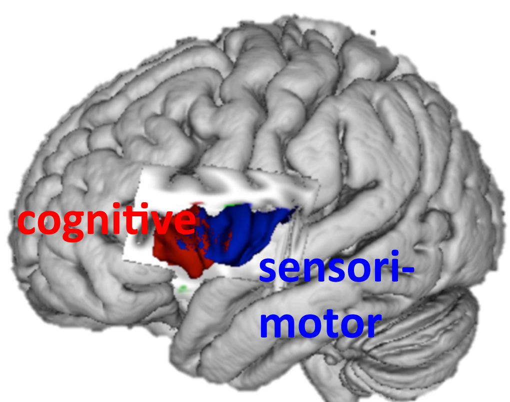
- **Different brain regions have different characteristics**

cytoarchitecture

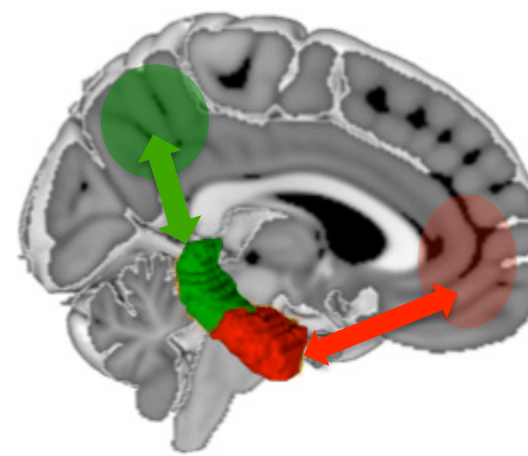


Kurth et al., 2010

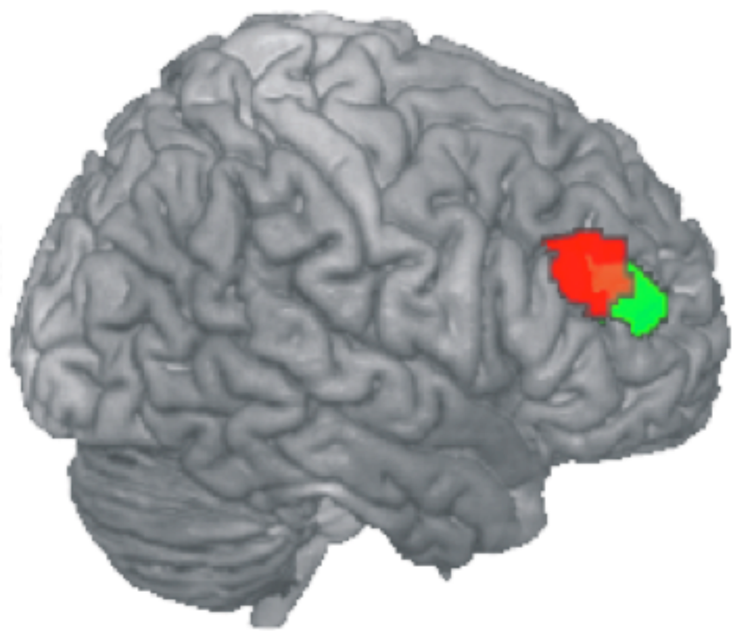
behavioral functions



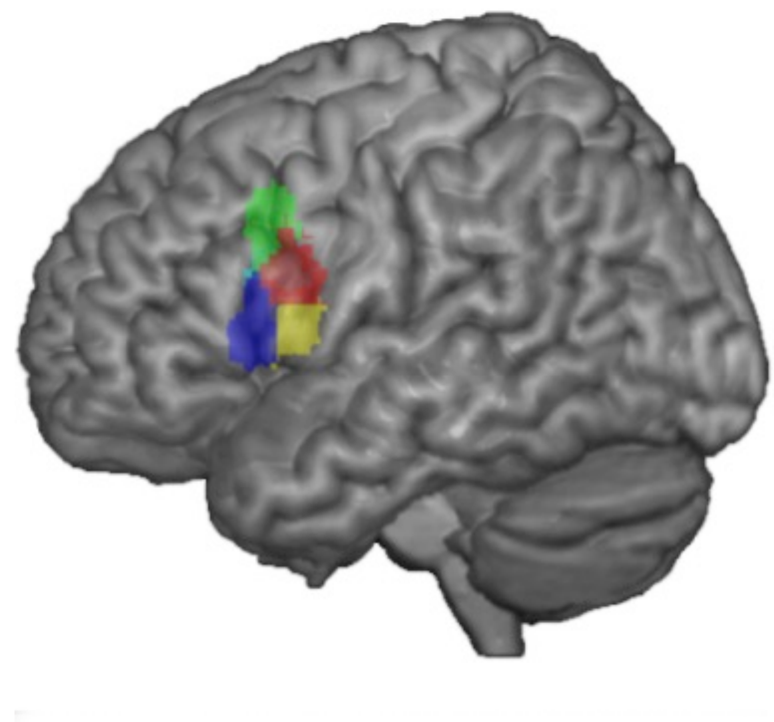
connectivity



Connectivity based parcellation (CBP)



Cieslik et al., 2013



Clos et al., 2013

MACM-CBP : Workflow

- Perform a MACM analysis for every individual voxel of the ROI

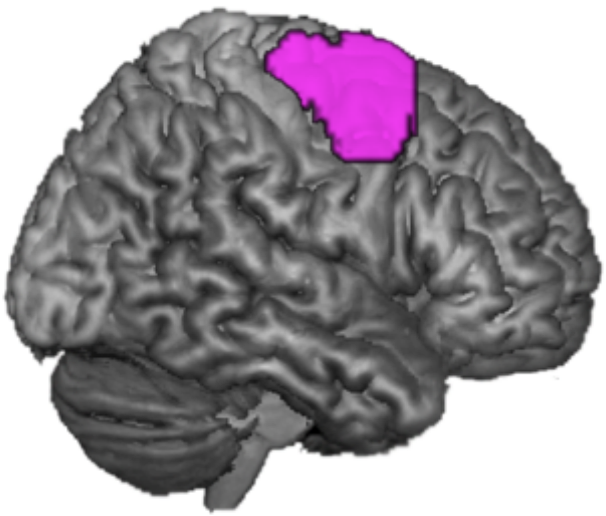
→ Connectivity matrix: Probability of co-activation for every voxel of the ROI with all voxels of the brain

- Examination of distances in connectivity between each pair of voxels within the VOI

→ (Dis)Similarity matrix: Correspondence between profiles

- Clustering: hierarchical or K-mean clustering

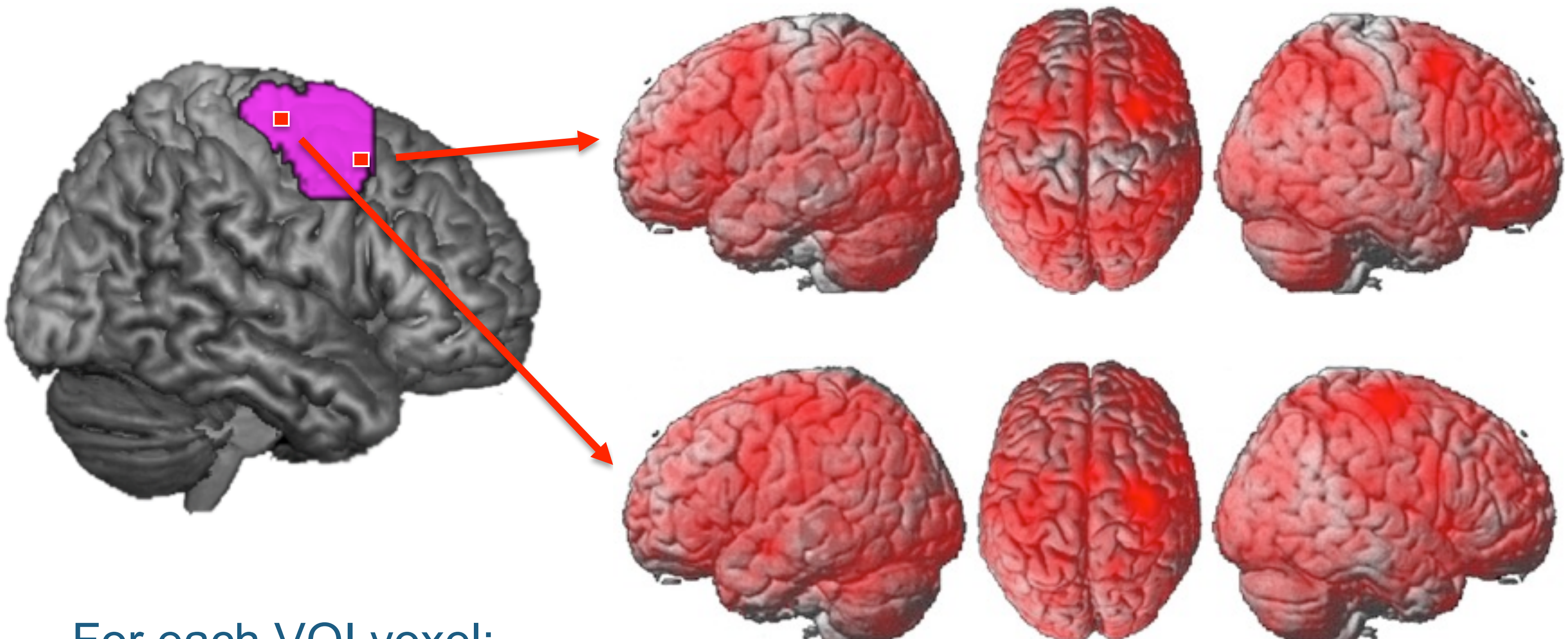
MACM-CBP of dorsal premotor cortex (PMd)



Are there functionally distinct subregions within the dorsal premotor cortex ROI ?

MACM-CBP of PMd

- Perform a MACM analysis for every individual voxel of the PMd ROI



For each VOI voxel:

- Identification of all experiments activating that voxel
- Computation of across-experiment convergence of co-activations

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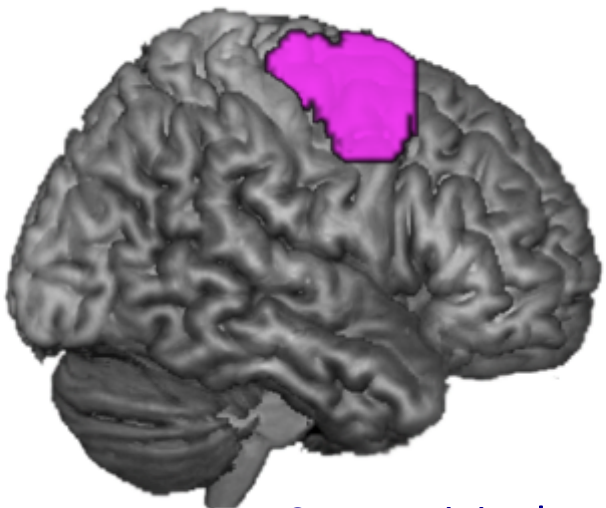
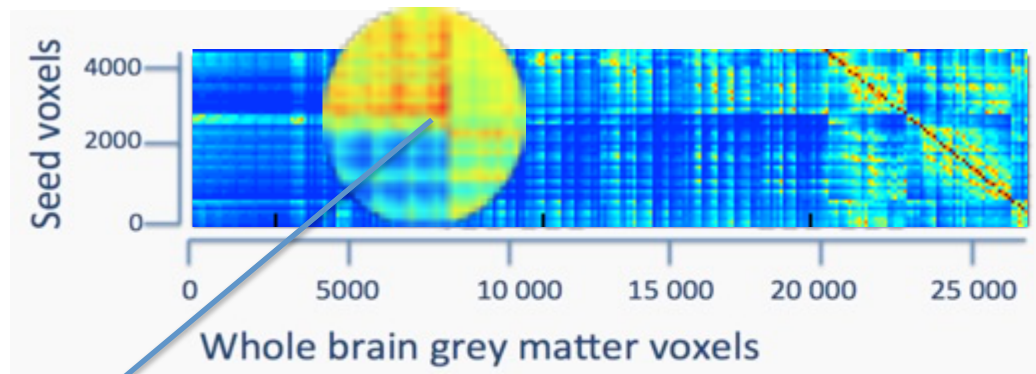
MACM-CBP of PMd

- Perform a MACM analysis for every individual voxel of the PMd ROI ➔ connectivity matrix





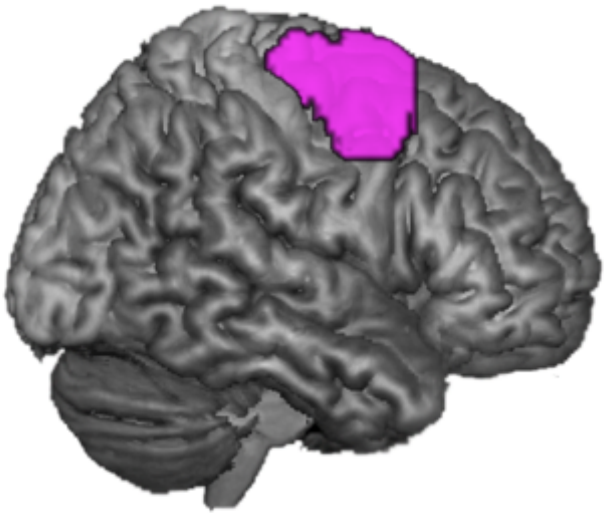
Connectivity between ROI voxel „x“ and brain voxel „y“

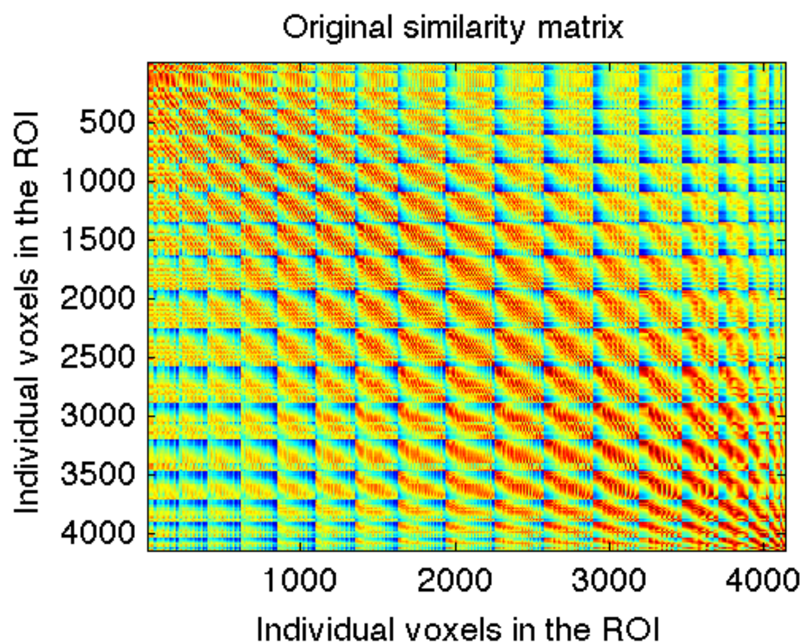
For each VOI voxel:

- Its connectivity profile (fingerprint)

MACM-CBP of PMd

- Calculation of distance in connectivity between each voxel pair of the PMd

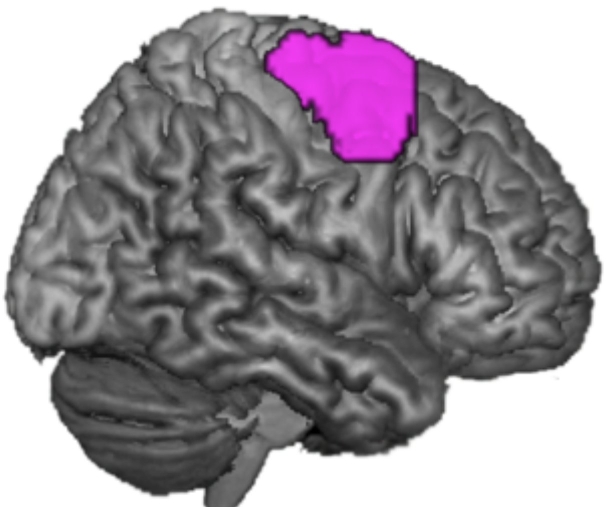


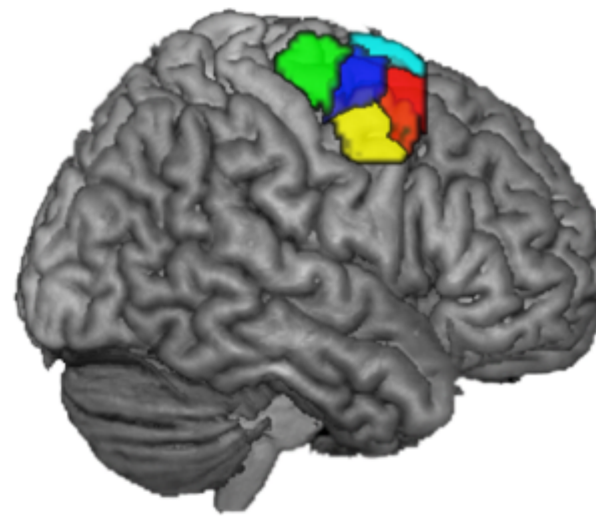


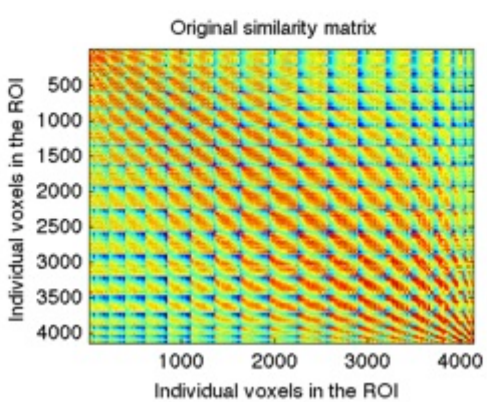
MACM-CBP of PMd

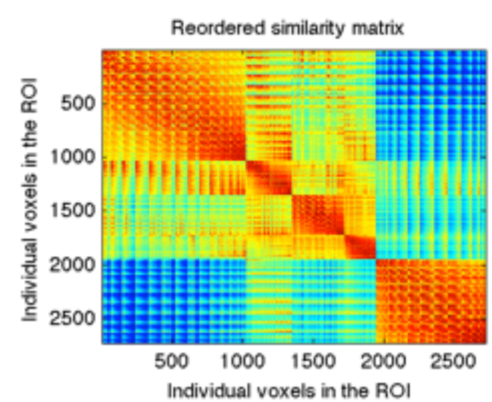
- Clustering:
  - Voxels with similar co-activation patterns →

    Voxels with patterns →

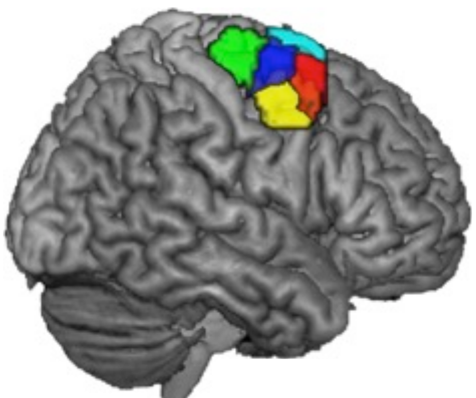




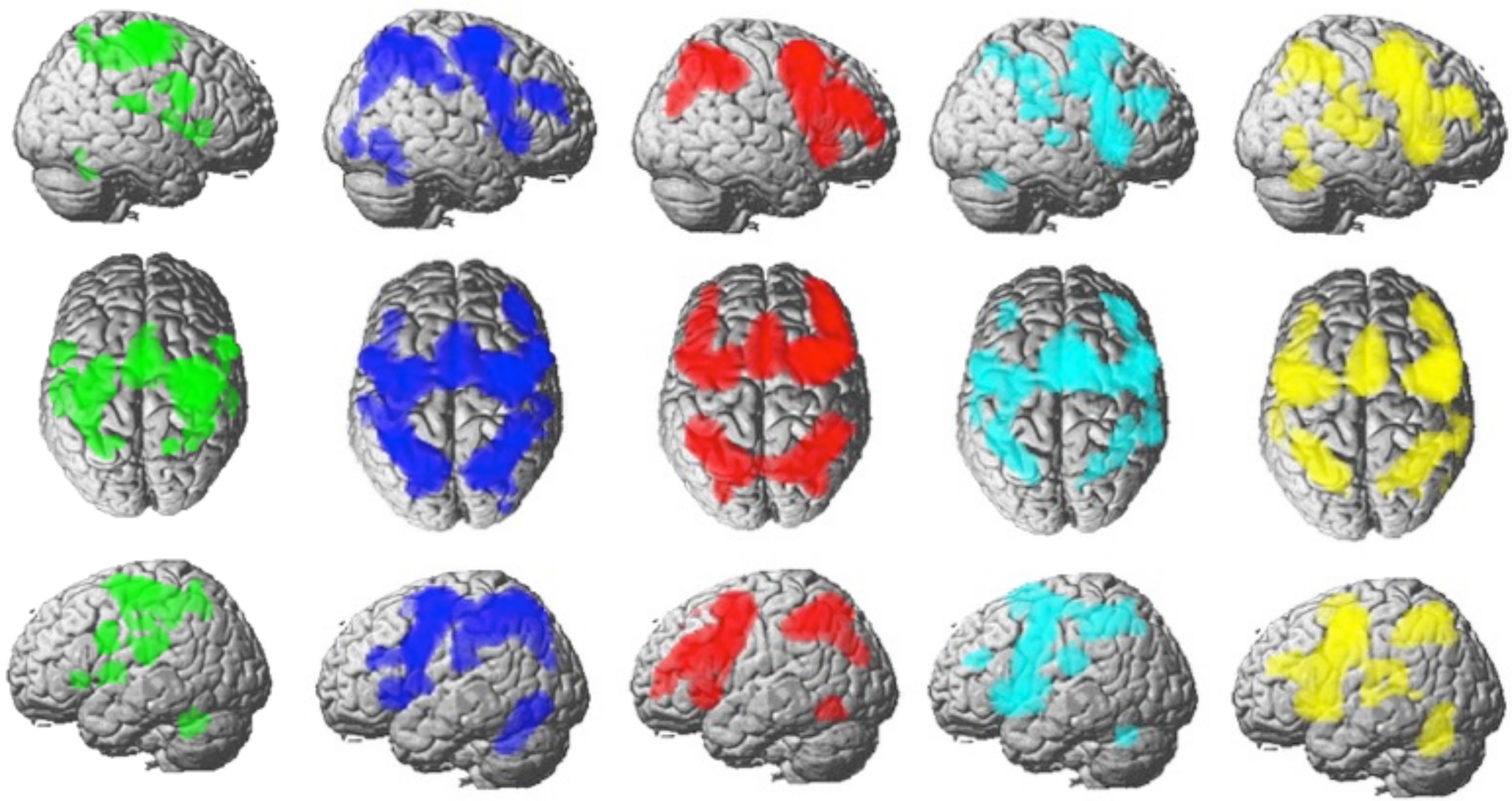




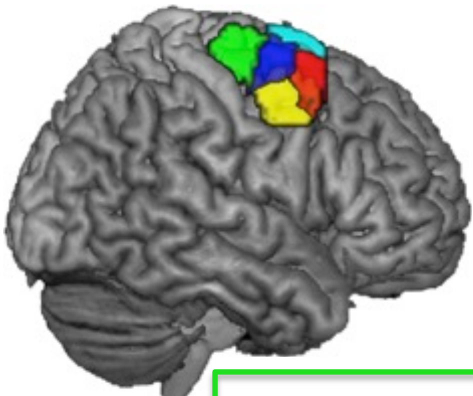
MACM-CBP of PMd



What are the connectivity differences driving this parcellation?



MACM-CBP of PMd



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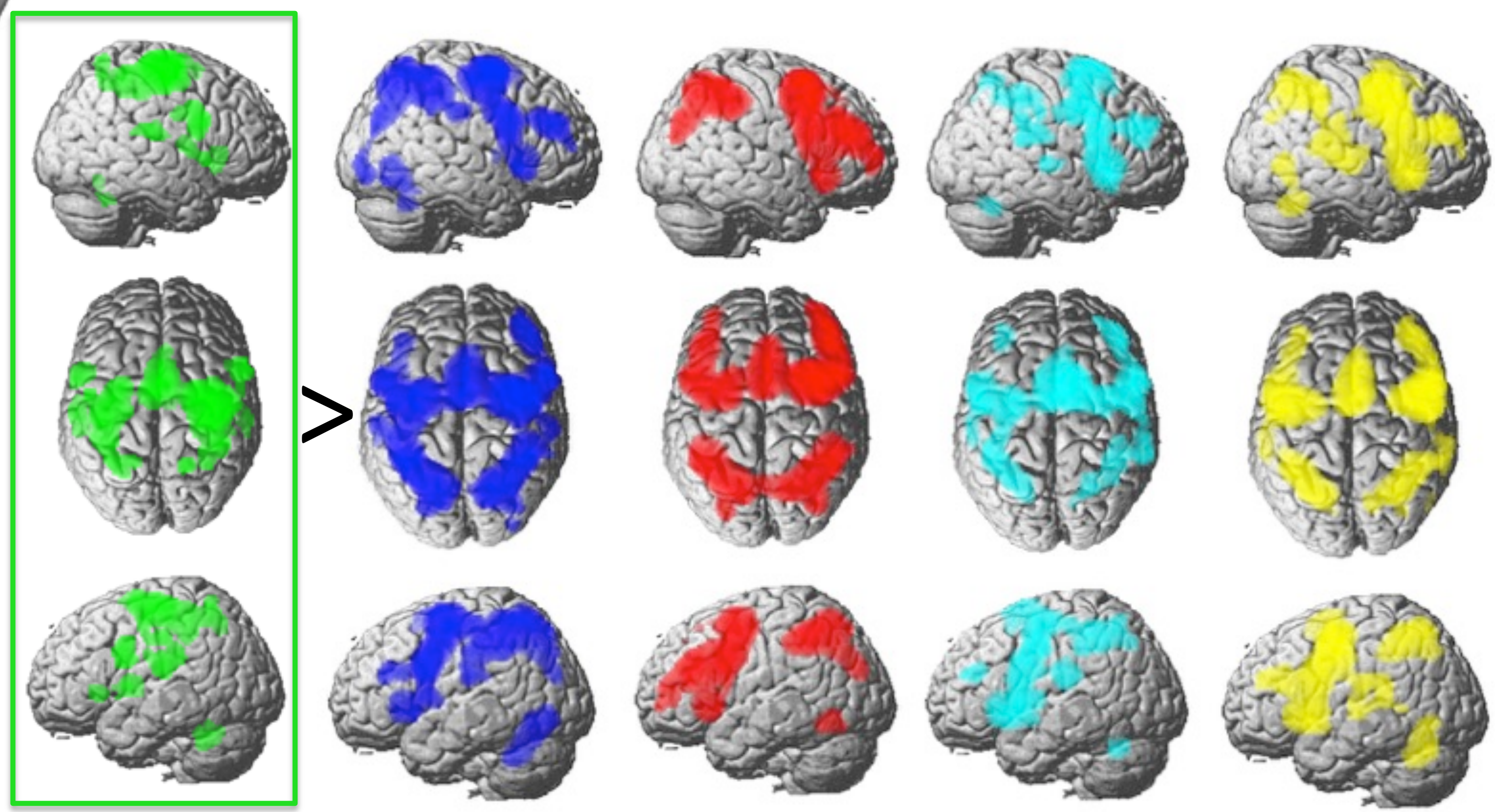
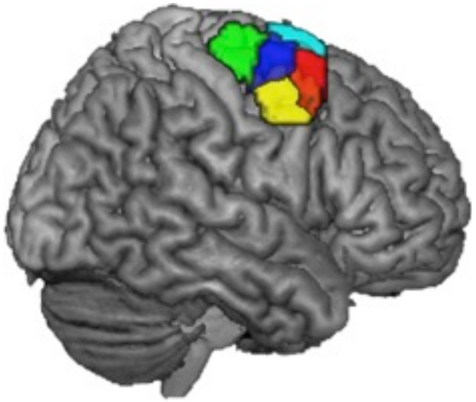


MACM-CBP of PMd



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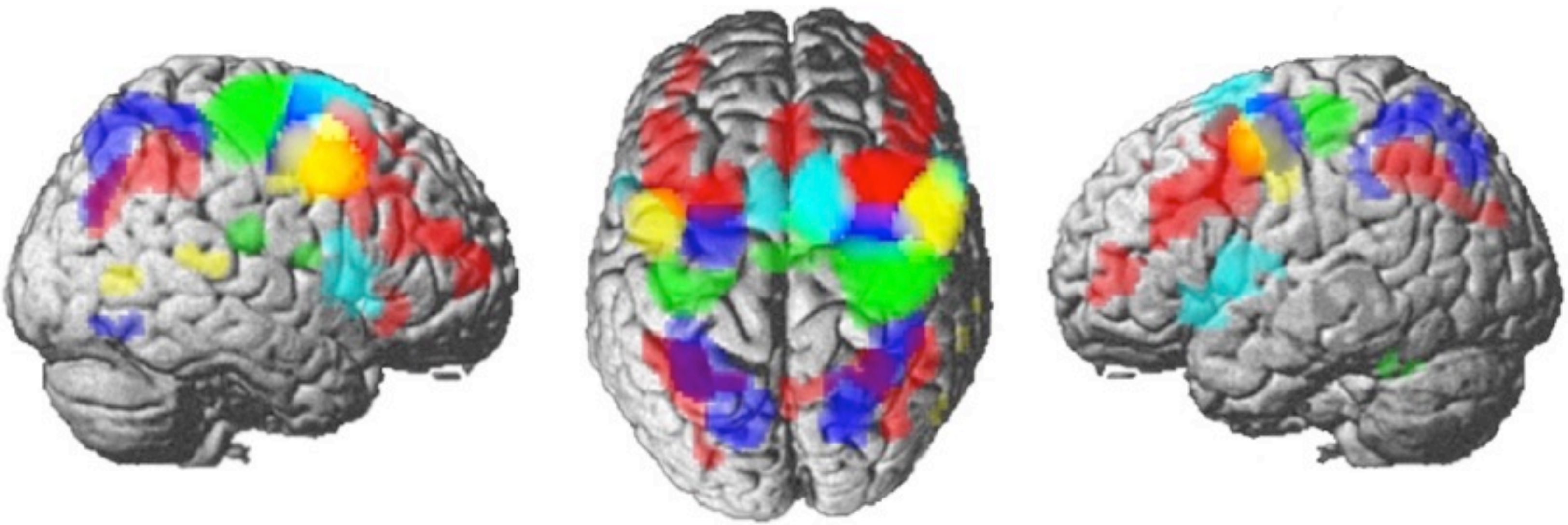
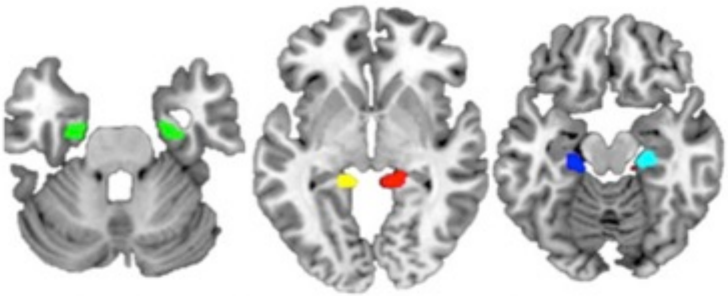
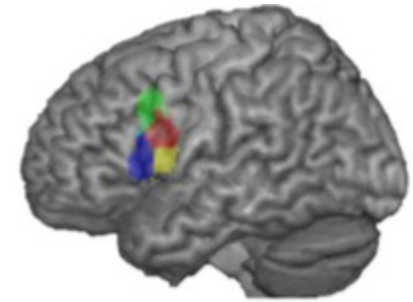


MACM-CBP projects

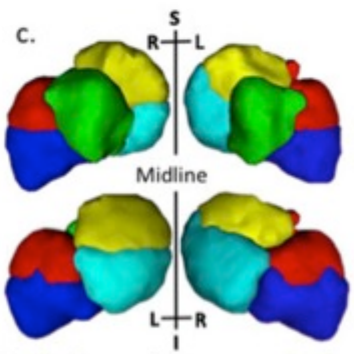


Subiculum: Chase et al., *Neuroimage 2015*

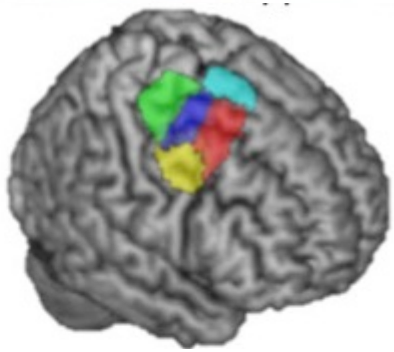
dmPFC: Eickhoff et al.,
Cerebral Cortex 2015



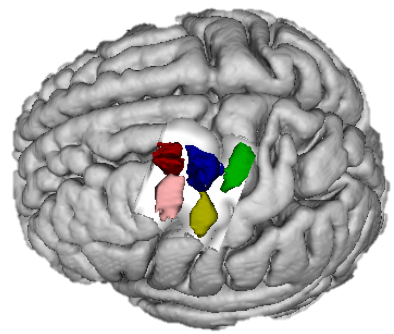
BA 44: Clos et al.,
Neuroimage 2015



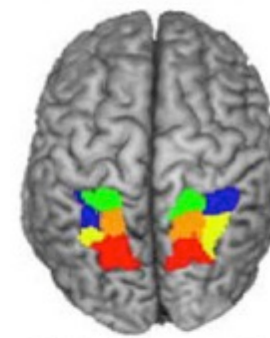
Pulvinar: Barron et al.,
Hum Brain Mapp 2015



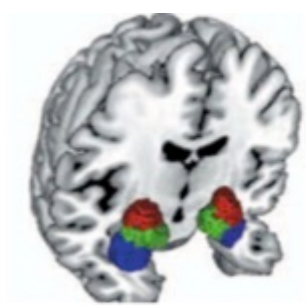
Right PMd: Genon et al.,
Cerebral Cortex 2017



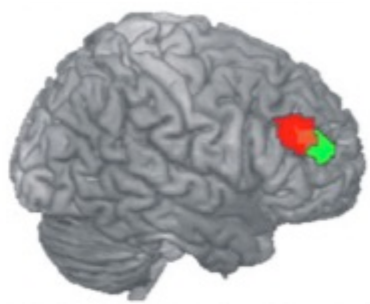
Left PMd: Genon et al.,
NeuroImage in press



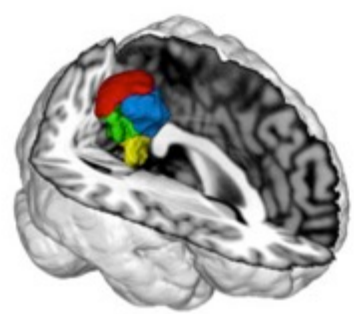
SPL: Wang et al.,
Hum Brain Mapp 2015



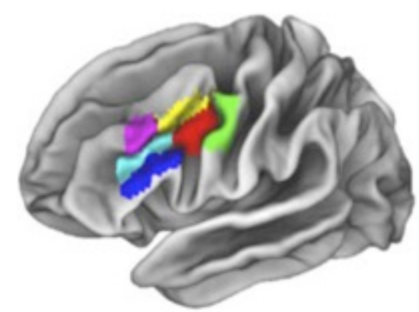
Amygdala: Bzdok et al.,
Hum Brain Mapp 2013



IFS / DLPFC: Cieslik et al.,
Cerebral Cortex 2013



PrC / PCC: Bzdok et al.,
Neuroimage 2015



IFJ: Muhle-Karbe et al.,
Cerebral Cortex 2015

Database for meta-analytical results

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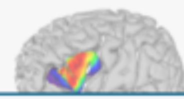
Meta-analytic maps are openly shared through the ANIMA database: **http://anima.fz-juelich.de**

ANIMA [beta edition]



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Study	Description	Size	Files
Cieslik et al. 2013 Is there "one" DLPFC in cognitive action control? Evidence for heterogeneity from co-activation-based parcellation. *Cerebral Cortex.* 23(11): 2677-2689.	This study shows that the right DLPFC as observed in 4 different experiments of executive action control may be subdivided into 2 distinct subregions -- an anterior-ventral and a posterior-dorsal one -- based on their whole-brain co-activation patterns across neuroimaging studies. The posterior subregion showed increased connectivity with bilateral intraparietal sulci, whereas the anterior subregion showed increased connectivity with the anterior cingulate cortex. Functional characterization revealed the anterior network to be more strongly associated with attention and action inhibition processes, whereas the posterior network was more strongly related to action execution and working memory.	1.6M	5
Cieslik et al., 2015 Three key regions for supervisory attentional control evidence from neuroimaging meta-analyses. *Neuroscience and Biobehavioural Reviews.* 48: 22-34.	We here investigated the core neural correlates of cognitive action control via coordinate-based meta-analyses of brain activity reported for the Stroop, spatial interference, stop-signal and go/no-go tasks. Our study revealed evidence for a pivotal role of the right anterior insula and right inferior frontal junction in supervisory attentional control, as these were the only two regions consistently involved in all four paradigm classes. Furthermore, the anterior midcingulate cortex and pre-supplementary motor area were commonly recruited by all but the go/no-go task.	1.6M	8
Clos et al. 2013 Tackling the multifunctional nature of Broca's region meta-analytically: co-activation-based parcellation of area 44. *Neuroimage.* 83: 174-188.	We investigated whether the functional heterogeneity of Broca's region is reflected in distinct modules within cytoarchitectonically-defined left area 44 using meta-analytic connectivity-based parcellation (CBP). Our analysis revealed five separate clusters within left area 44. A post-hoc functional characterization and functional connectivity analysis of these five clusters was then performed, revealing specific and distinct functional	2.6M	23

Summary

- Topic based meta-analyses: identify networks associated to a specific function
- Location based meta-analyses: identify networks co-activating with a specific region across different functions
- Meta-analytic connectivity modeling offers an approach to task-based functional connectivity
- Co-activation based parcellation enables to identify cortical modules in a data-driven fashion

Thank you!

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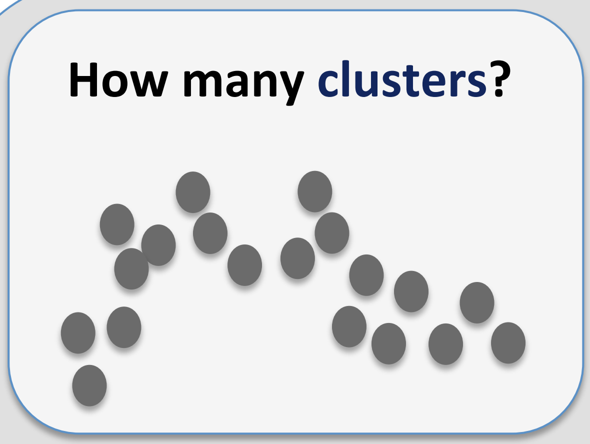
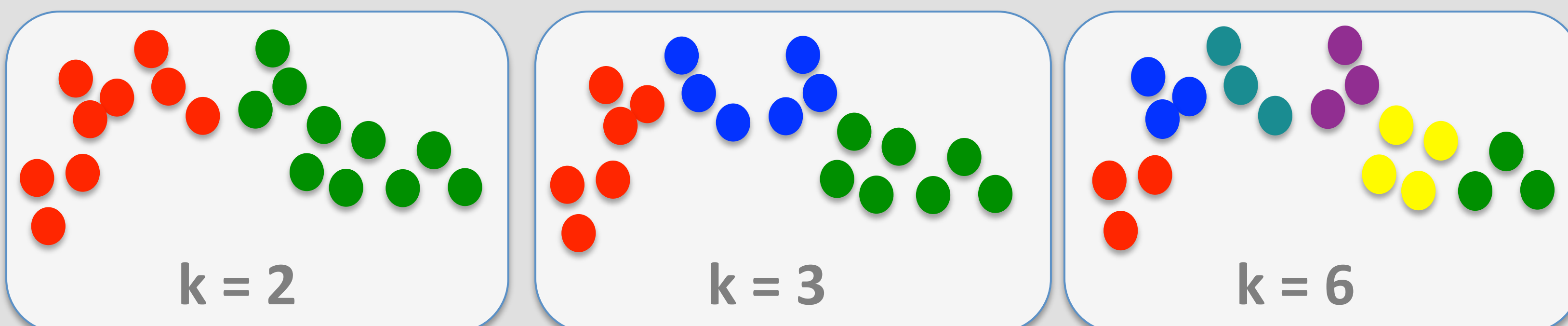
CBP: how many clusters ?



→ **Search for several k:**

e.g.: 2 -> 8



CBP: how many clusters ?

<u>Information theory</u> <u>consistency</u> <u>separation</u>