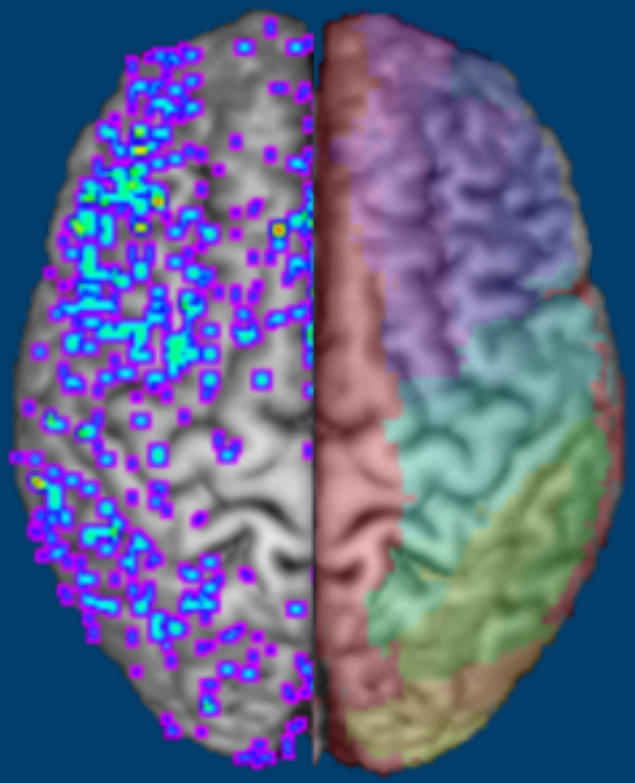
Co-activation mapping and Parcellation



Sarah Genon

Brain & Behaviour

Brain & Behaviour

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META-ANALYSES

- **Topic based meta-analyses:**

"Working Memory"

derive brain regions consistently found across studies investigating a specific behavioral function

- **Location based meta-analyses:**

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META-ANALYSES

- **Topic based meta-analyses:**

  derive brain regions consistently found across studies investigating a specific behavioral function

- **Location based meta-analyses:**

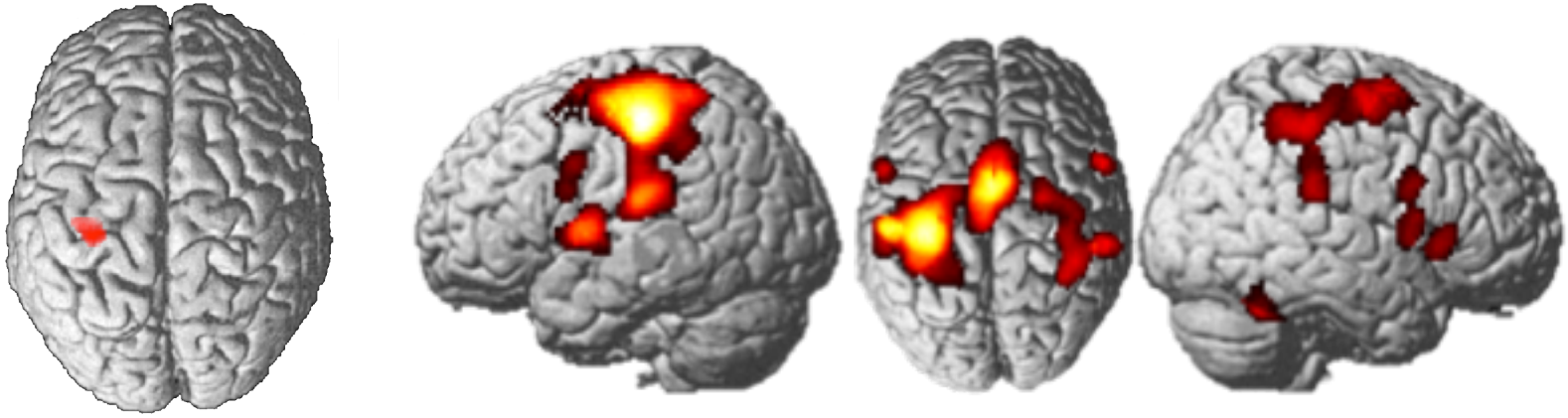
  derive brain regions consistently found to activate together with a specific region across studies investigating different behavioral functions

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 „

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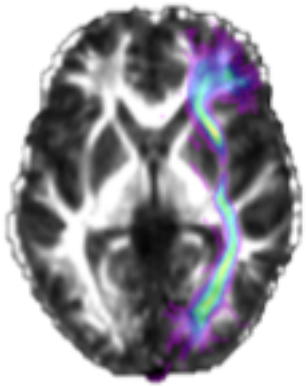
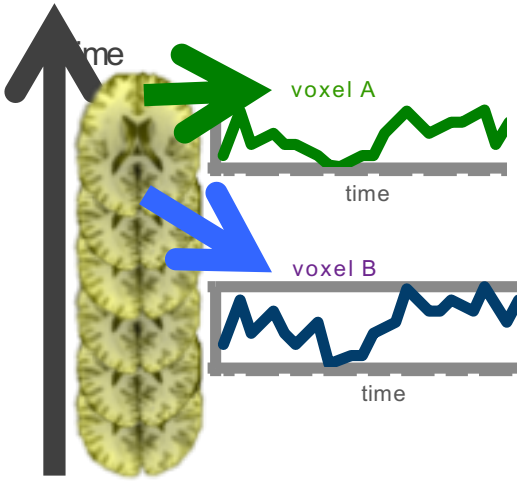
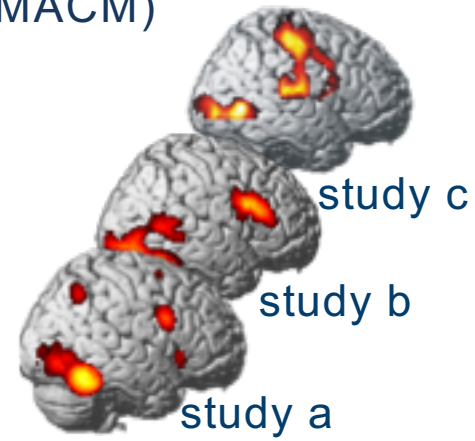
MRI/PET-BASED CONNECTIVITY

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



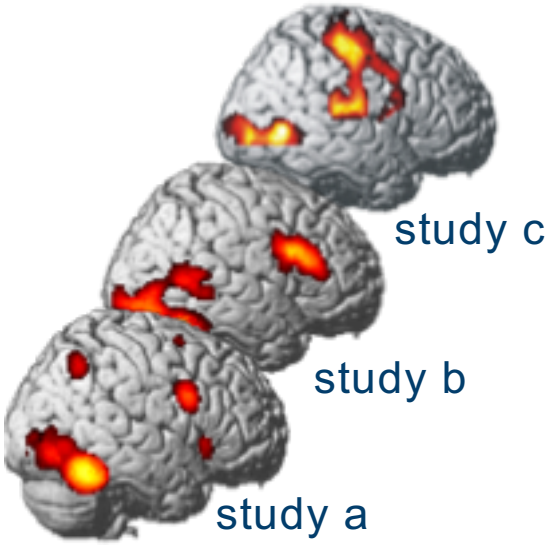




MACM

Location based meta-analyses:

- Co-activations consistently found across different experiments
- Meta-analysis as a tool to derive functional connectivity



Meta-**A**nalytic

Connectivity **M**odeling

(MACM)

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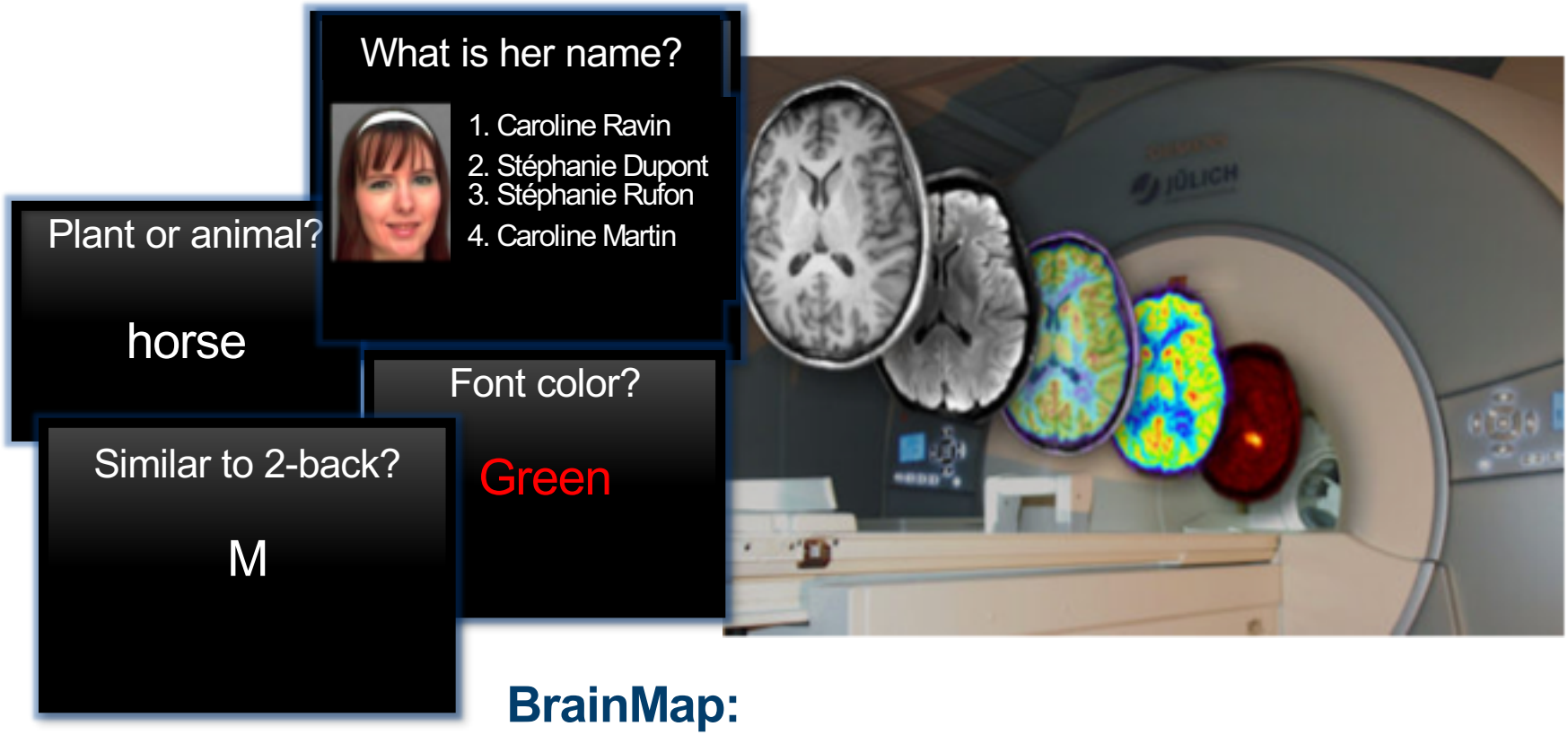
Aggregation of activation experiments

10^4 activations experiments



BrainMap:

> 3200 papers **(> 16380 experiments)**

Neurosynth:

> 11400 papers

Genon et al., 2018, TICS

BrainMap database

http://brainmap.org/

3294 papers
16383 experiments
127210 locations

- Coordinates in stereotactic space
- Experimental information

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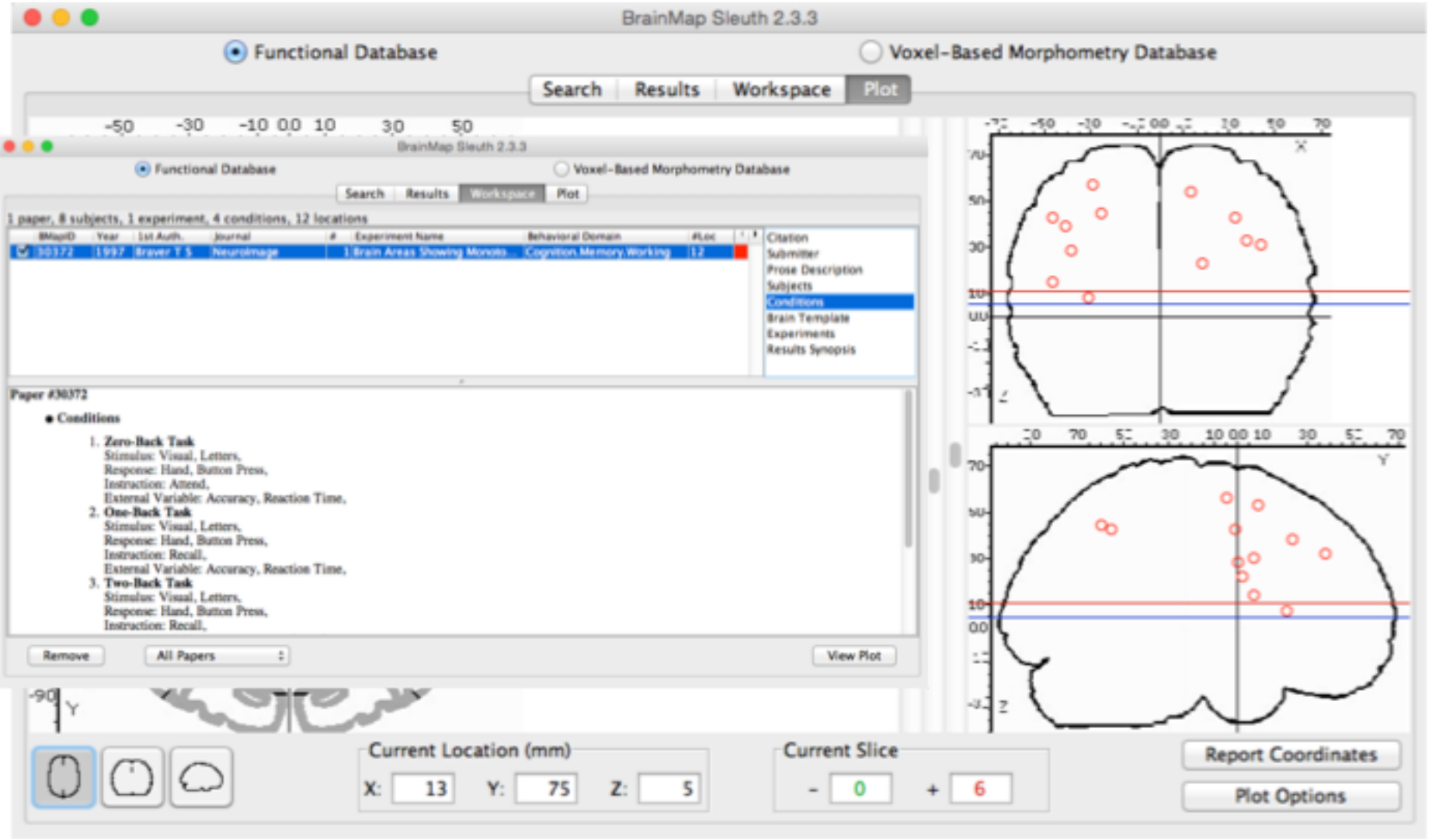
BrainMap database



brainmap.org

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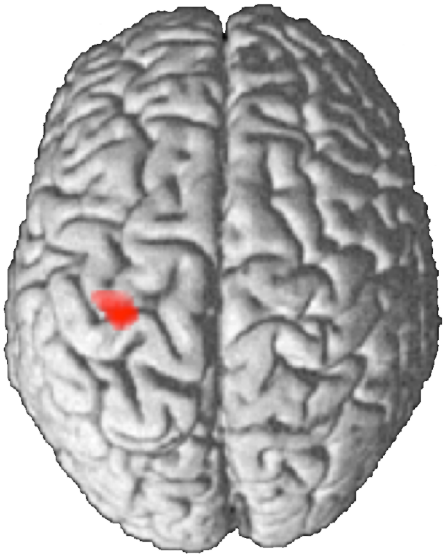
MACM : WORKFLOW

- 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 ?

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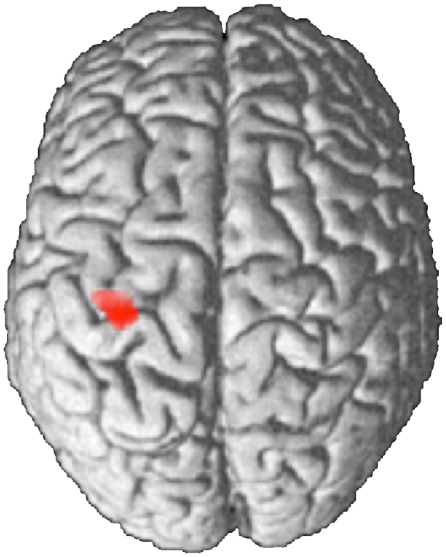
Co-activation of left M1

- Identify all experiments activating the seed region

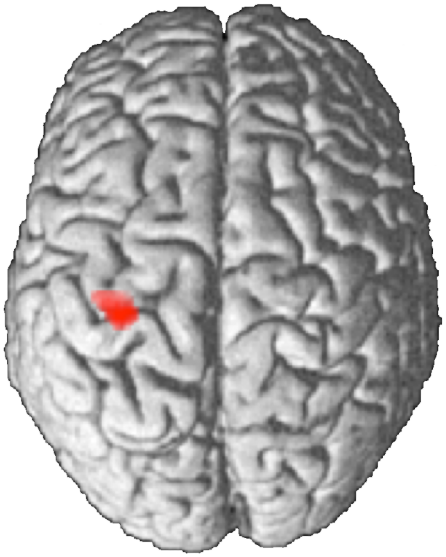


155 experiments activating left M1

	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



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☑	30015	2000	Desmurget M	Experimental Brain Re...	4	RAND - STAT	Perception.Vision.Moti...	5
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☑	30016	2001	Desmurg				Action.Execution	14
☐	30016	2001	Desmurg				Perception.Vision.Moti...	3
☐	30020	2000	Ehrsson				Action.Execution	9
☑	30020	2000	Ehrsson				Action.Execution	14
☐	30020	2000	Ehrsson				Action.Execution	17
☑	30020	2000	Ehrsson				Action.Execution	5
☐	30020	2000	Ehrsson				Action.Execution	4
☐	30020	2000	Ehrsson				Action.Execution	13
☐	30020	2000	Ehrsson				Action.Execution	3
☐	30022	2001	Gosain A				Action.Execution	2
☑	30022	2001	Gosain A				Action.Execution	2
☑	30026	1998	Sadato N				Perception.Somesthesi...	27
☐	30026	1998	Sadato N				Perception.Somesthesi...	24
☐	30026	1998	Sadato N				Perception.Somesthesi...	7
☑	30026	1998	Sadato N				Perception.Somesthesi...	15
☐	30026	1998	Sadato N				Perception.Somesthesi...	12
☐	30026	1998	Sadato N				Perception.Somesthesi...	10
☐	30026	1998	Sadato N				Perception.Somesthesi...	3
☐	30026	1998	Sadato N				Perception.Somesthesi...	10
☐	30026	1998	Sadato N				Perception.Somesthesi...	5
☐	30026	1998	Sadato N				Perception.Somesthesi...	7
☐	30026	1998	Sadato N				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
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☐	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
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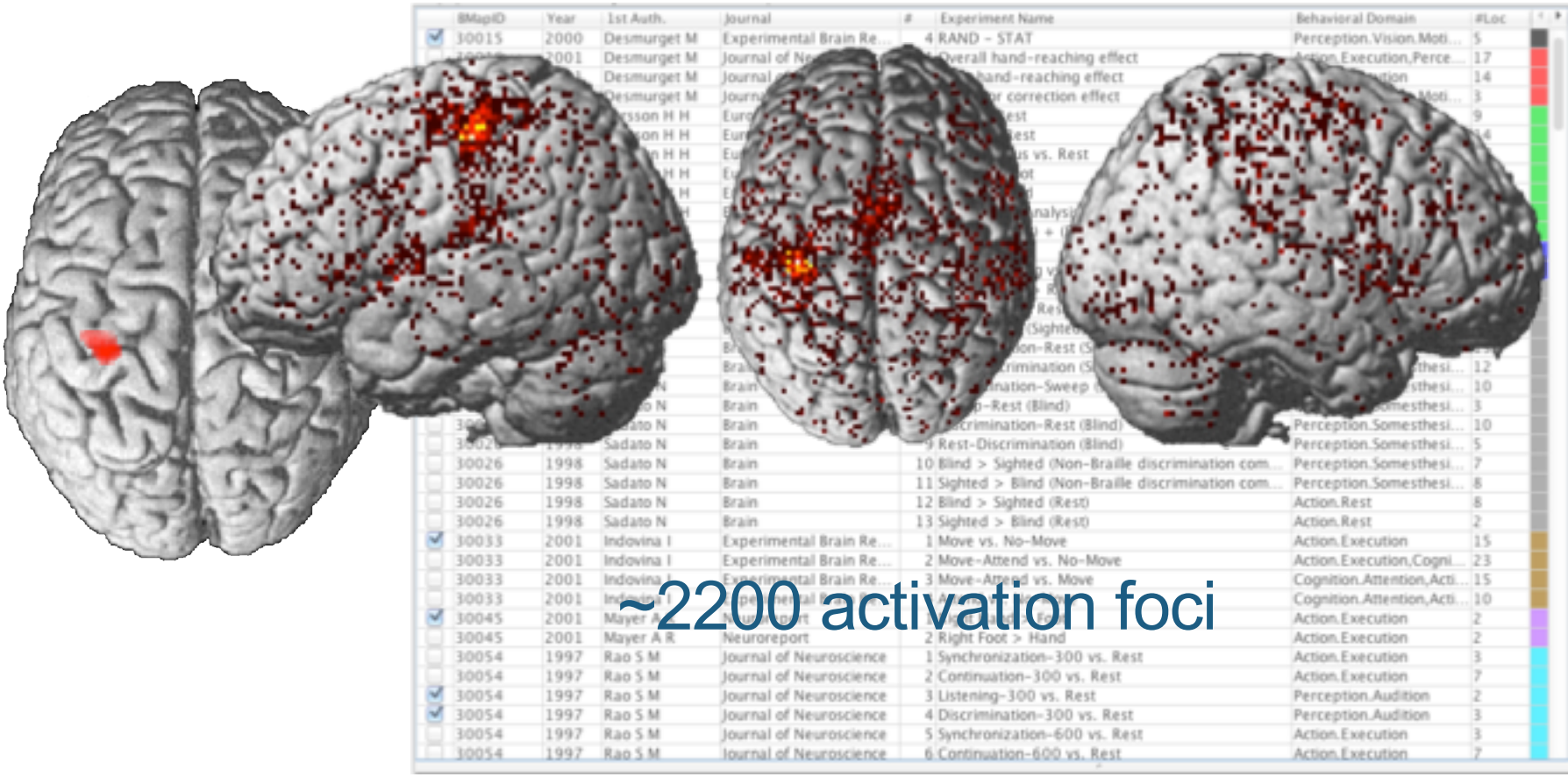
☐	30054	1997	Rao S M	Journal of Neuroscience	5	Synchronization-600 vs. Rest	Action.Execution	3
☐	30054	1997	Rao S M	Journal of Neuroscience	6	Continuation-600 vs. Rest	Action.Execution	7

Co-activation of left M1

- Extract all coordinates from 155 experiments



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30015	2000	Desmurget M	Experimental Brain Re...	4	RAND - STAT	Perception.Vision.Moti...	5
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		Desmurget M	Journal...		hand-reaching effect	...tion	14
		Desmurget M	Journ...		r correction effect	...Moti...	3
		...sson H H	Euro...		...est		9
		...son H H	Eur...		...est		4
		...n H H	Eu...		...us vs. Rest		
		...H H	E...		...ot		
		...H H	E...		...		
		...H	B...		...nalysis		
					...		
					...(Sighted		
					...on-Rest (S...		
					...crimination (S...	...thesi...	12
		...N	Brain		...ination-Sweep (	...sthesi...	10
		...o N	Brain		...p-Rest (Blind)	...Somesthesi...	3
		...ato N	Brain		...crimination-Rest (Blind)	Perception.Somesthesi...	10
		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
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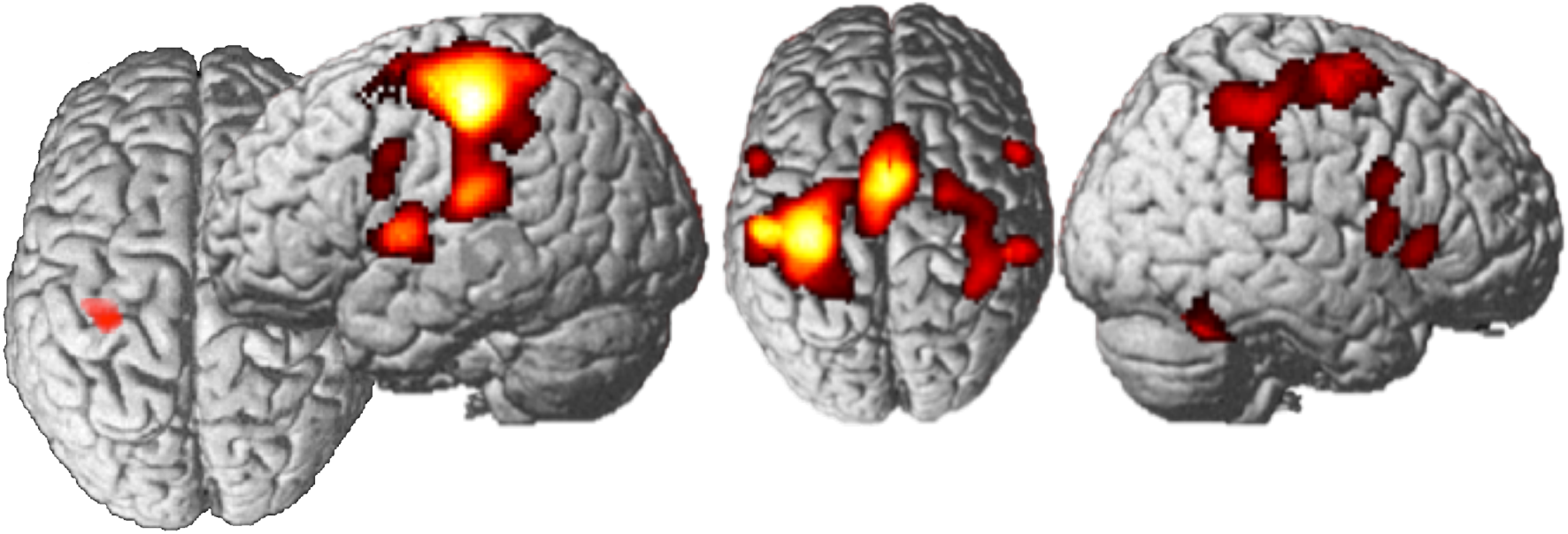
~2200 activation foci

CO-ACTIVATION OF LEFT M1

- Perform a meta-analysis across identified experiments



Network significantly co-activating with M1

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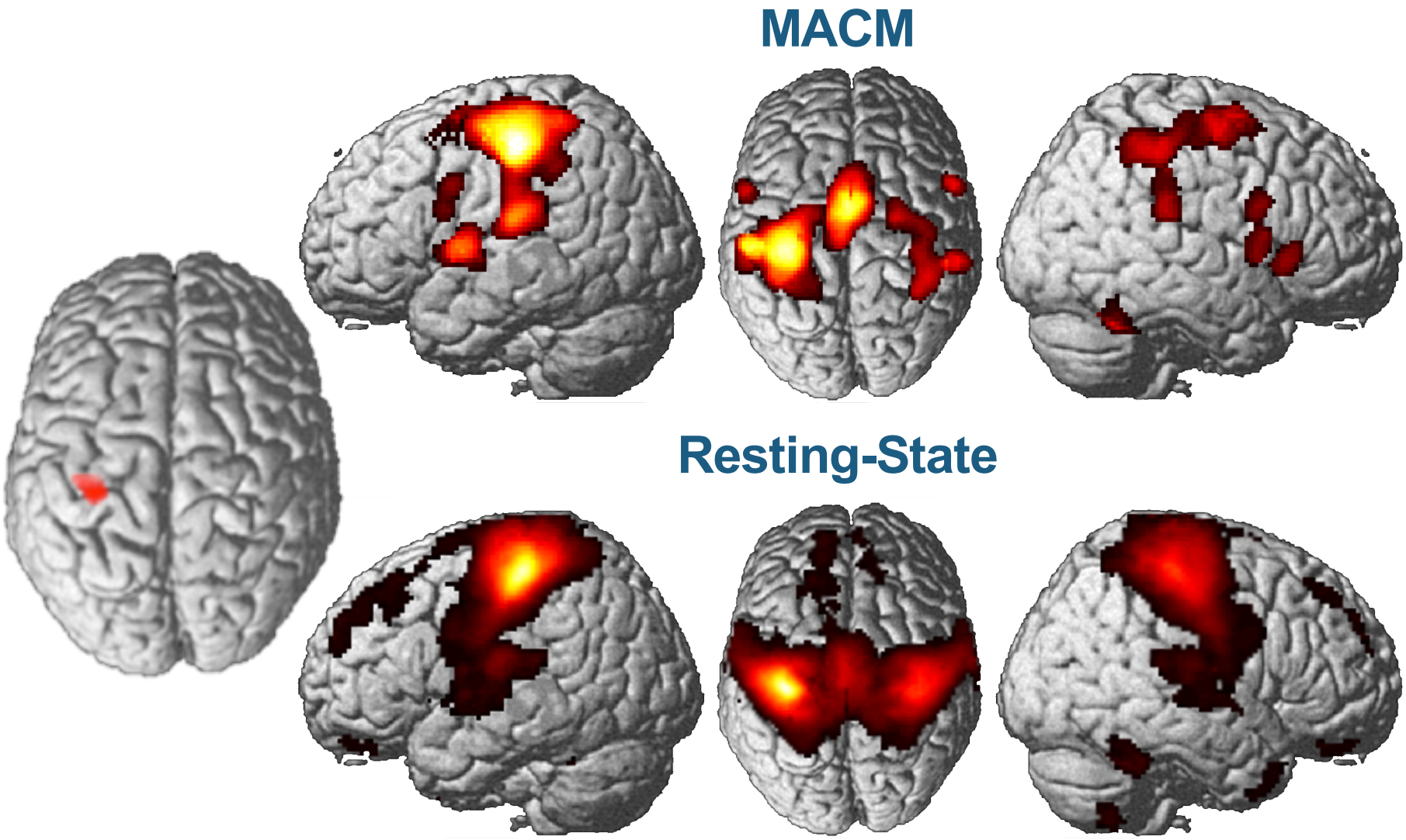
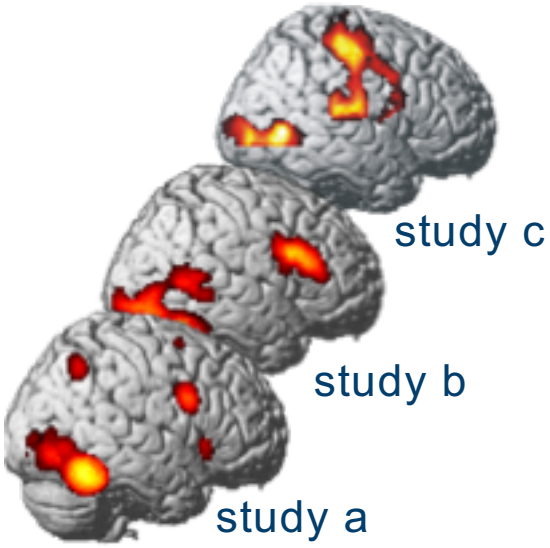
COMPARISON TO RESTING STATE FUNCTIONAL CONNECTIVITY



MACM

Location based meta-analyses:

- Co-activations consistently found across different experiments
- Meta-analysis as a tool to derive functional connectivity



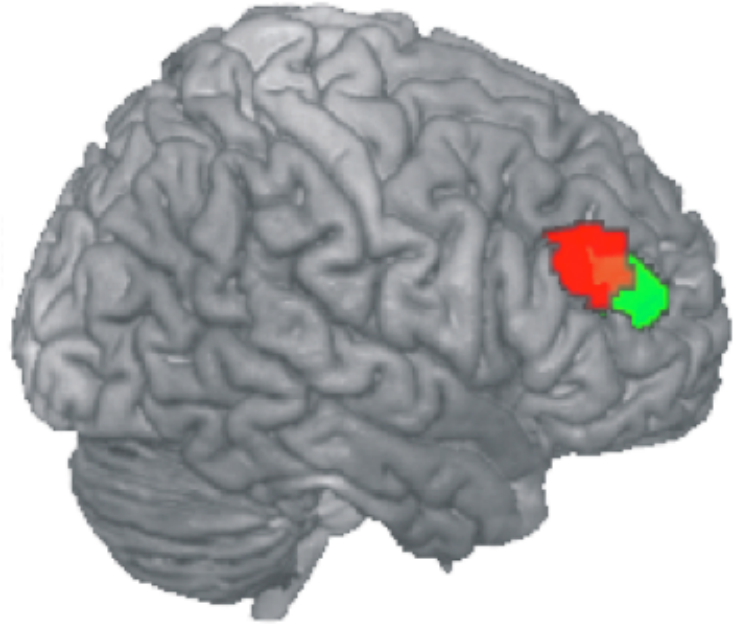
Meta-**A**nalytic

Connectivity **M**odeling

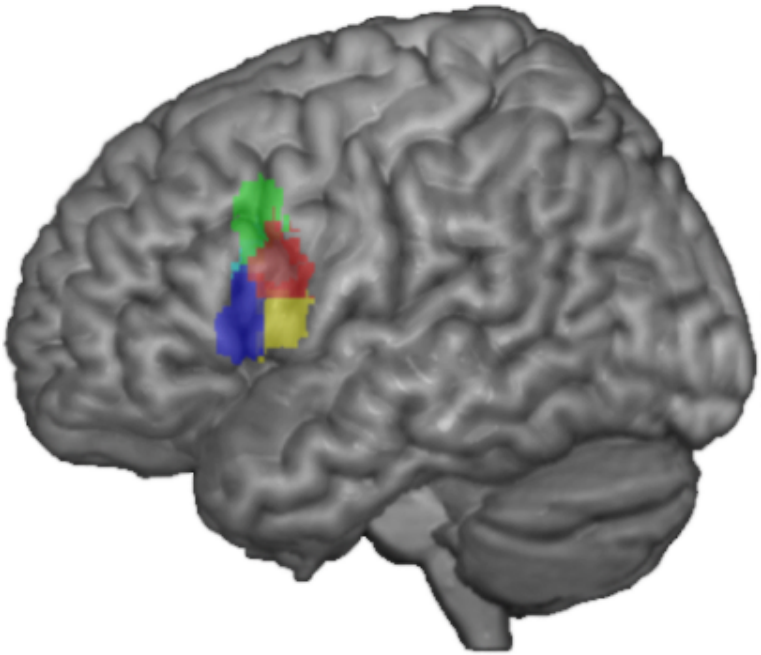
(MACM)

➔ **Functional connectivity to parcellate the brain**

CONNECTIVITY BASED PARCELLATION (CBP)



Cieslik et al., 2013

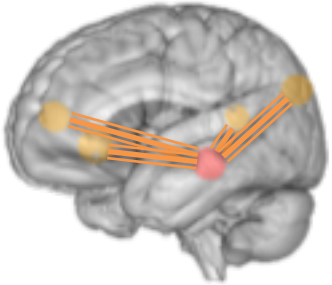


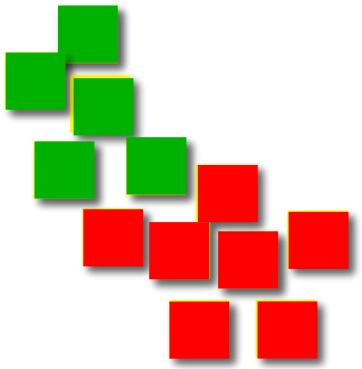
Clos et al., 2013

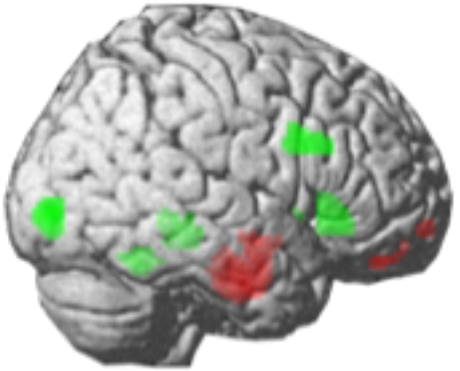
Connectivity-based parcellation (CBP)

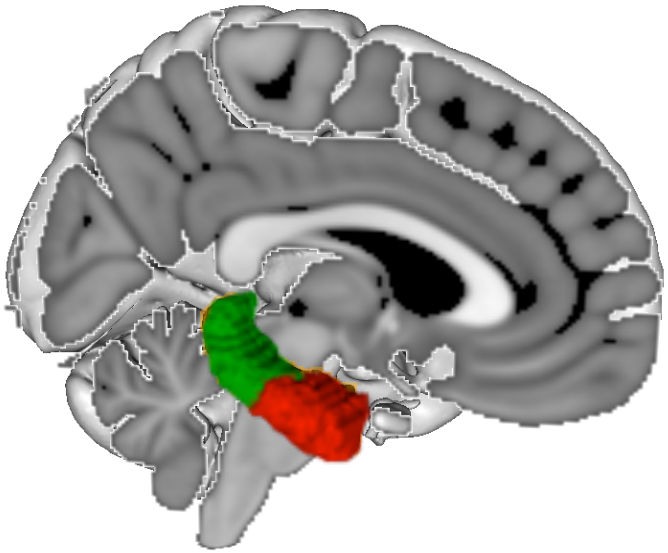
Neuroimaging scanner

Connectivity









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MACM-CBP : WORKFLOW

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

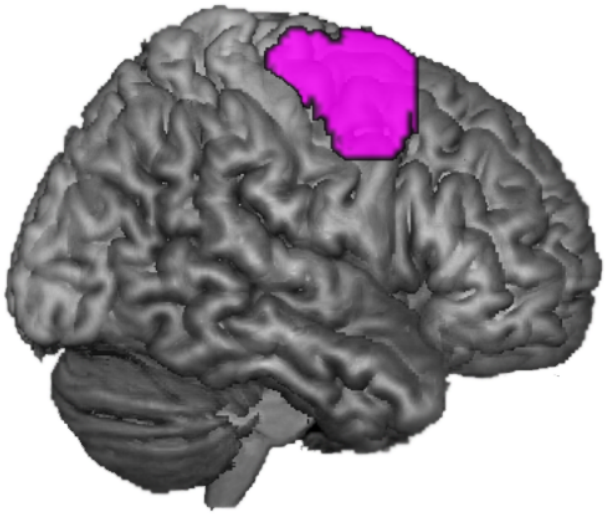
  → Connectivity matrix: Probability of co-activation for every voxel of the ROI with all voxels of the brain

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

  → (Dis)Similarity matrix: Correspondence between profiles

- Clustering: e.g. K-mean clustering

MACM-CBP OF DORSAL PREMOTOR CORTEX (PMD)



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

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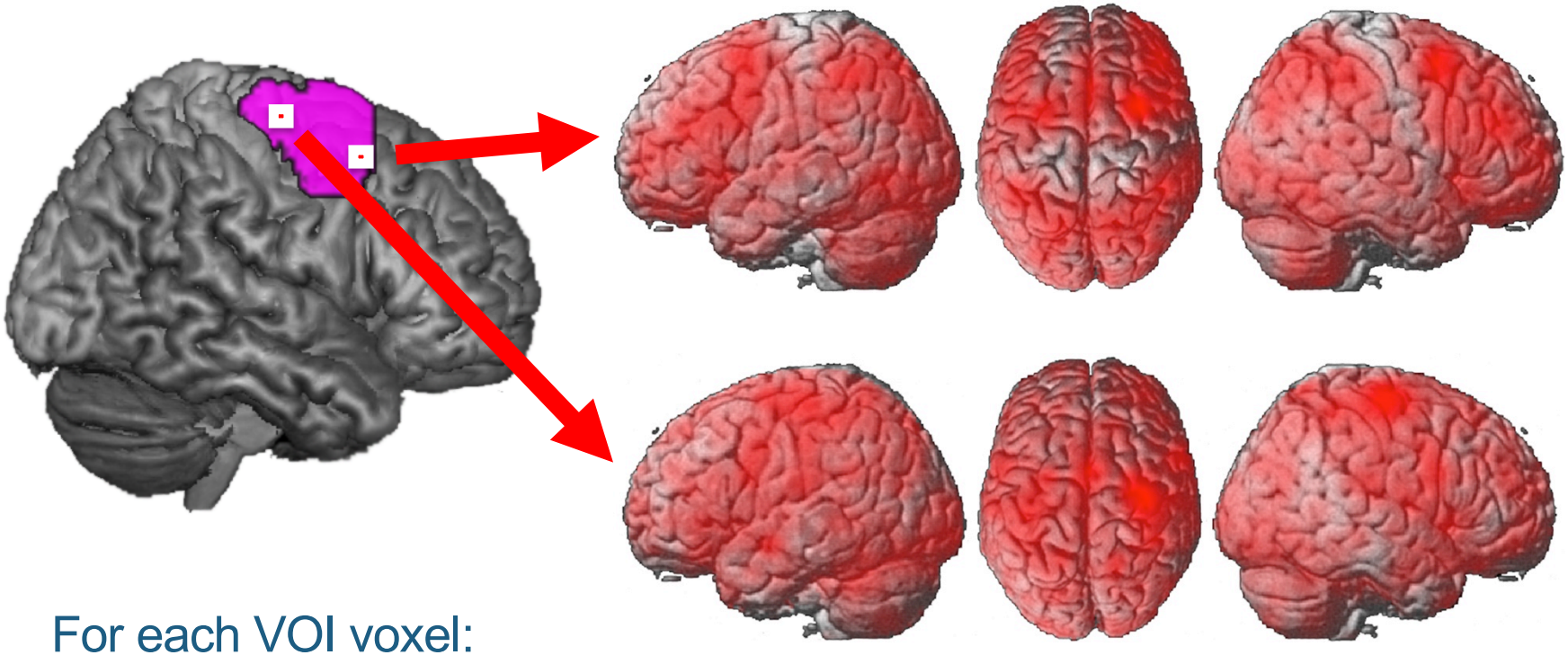
MACM-CBP OF PMD

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

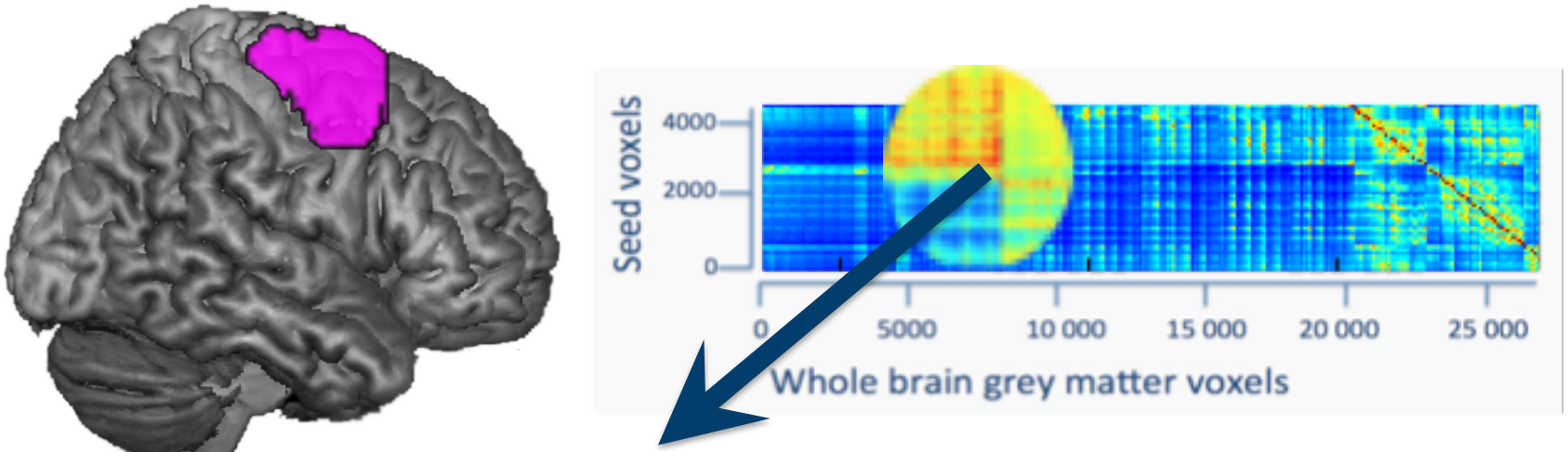


For each VOI voxel:

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

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)

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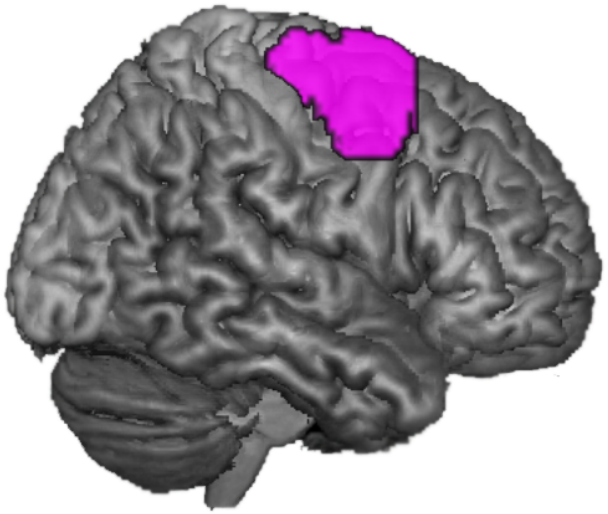
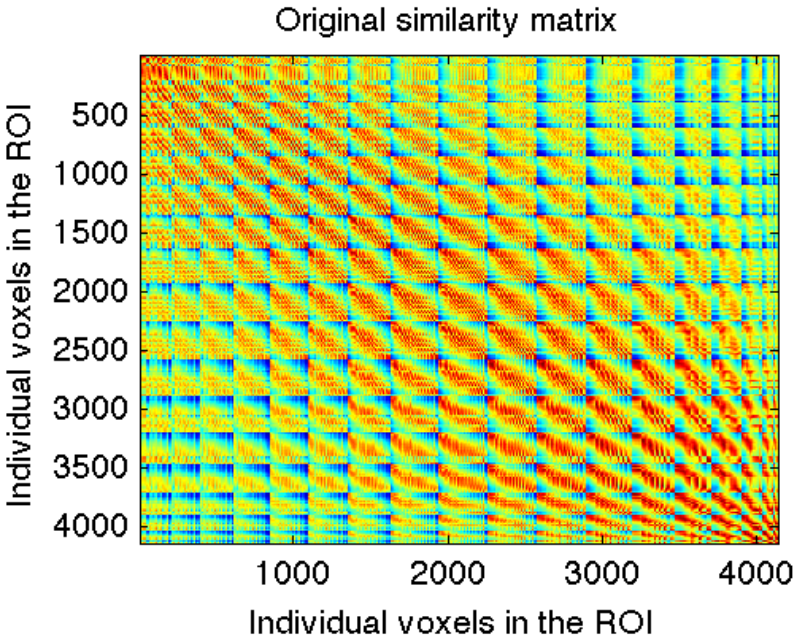
MACM-CBP OF PMD

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





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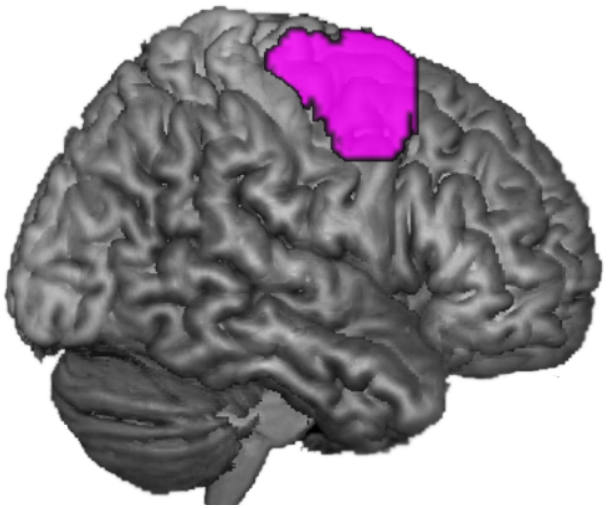
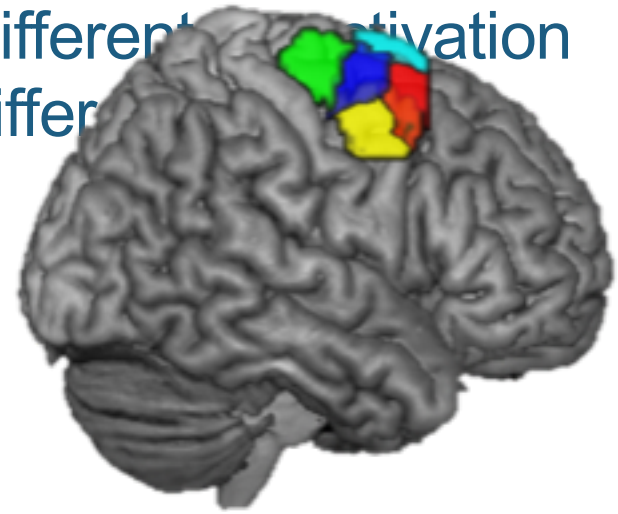
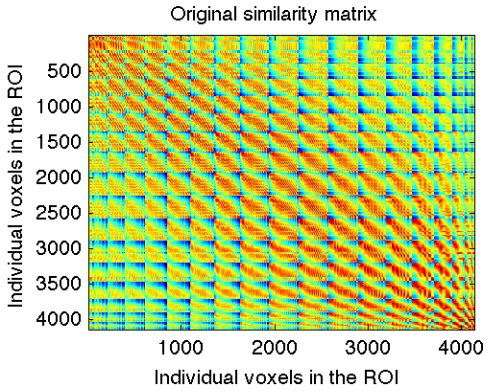
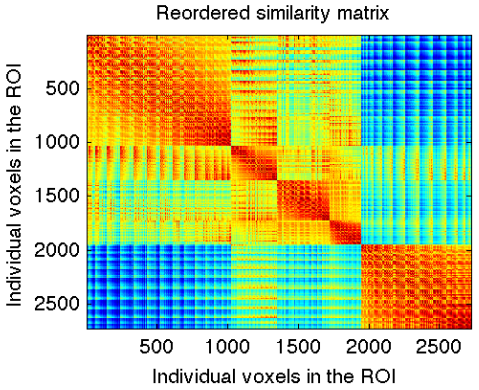
MACM-CBP OF PMD

- Clustering:
  - Voxels with similar co-activation patterns → same cluster
  - Voxels with different co-activation patterns → differ

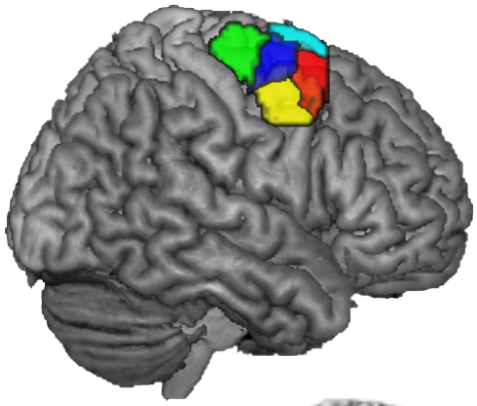




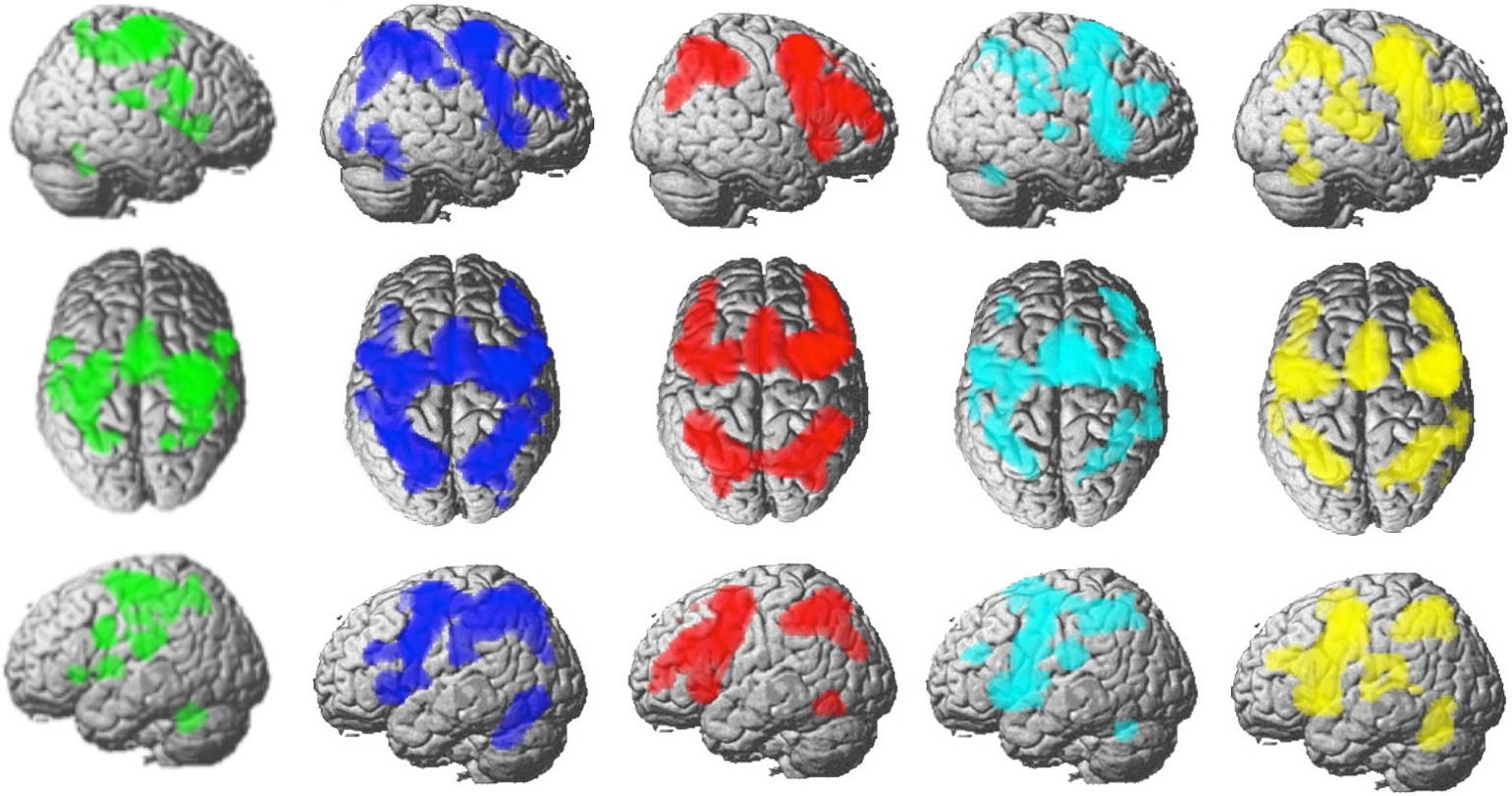




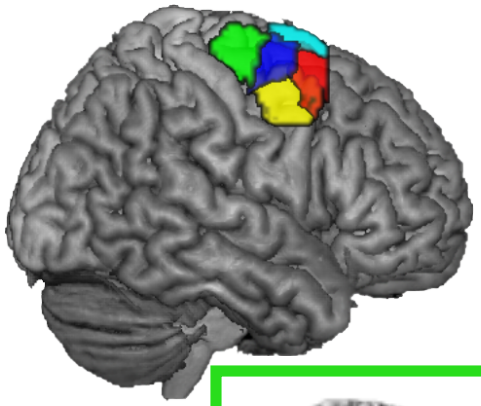
MACM-CBP OF PMD



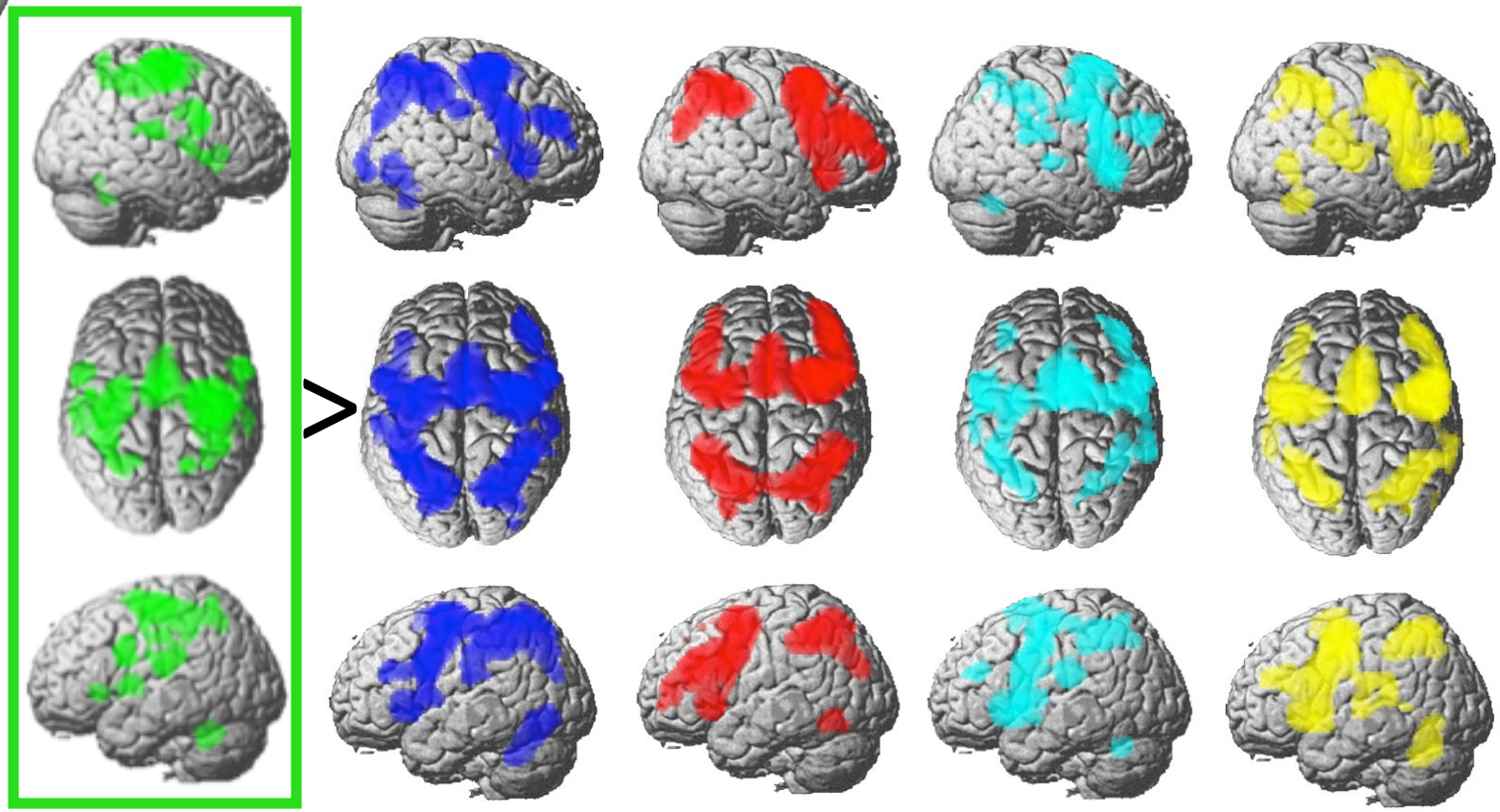
What are the connectivity differences driving this parcellation?



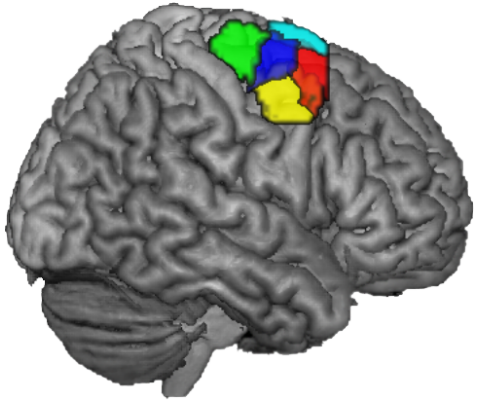
MACM-CBP OF PMD



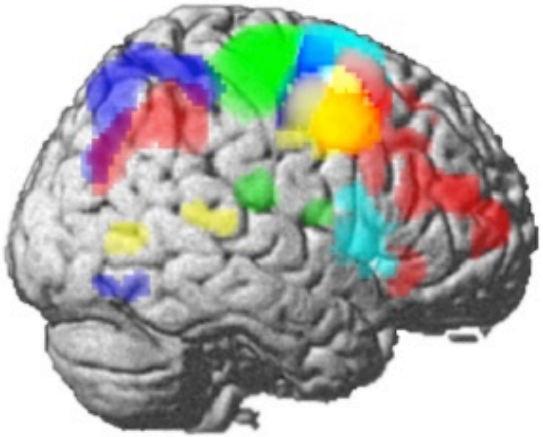
What are the connectivity differences driving this parcellation?

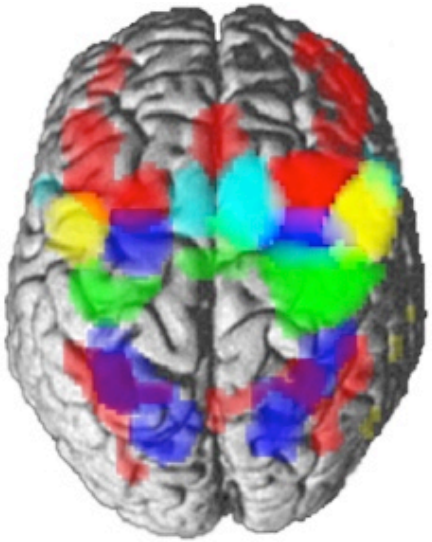


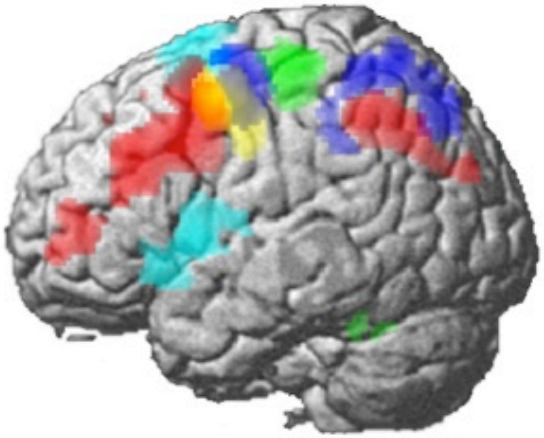
MACM-CBP OF PMD



What are the connectivity differences driving this parcellation?

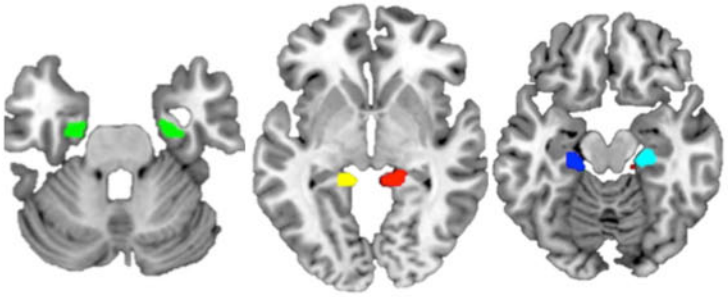




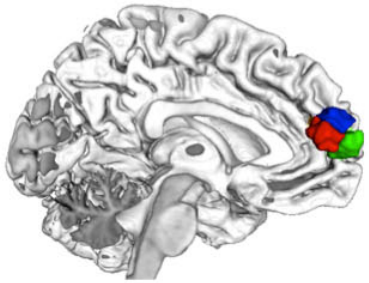


JÜLICH
Forschungszentrum

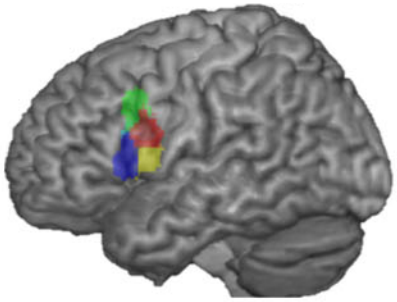
MACM-CBP PROJECTS



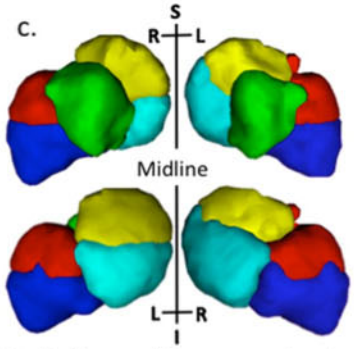
Subiculum: Chase et al., *Neuroimage 2015*



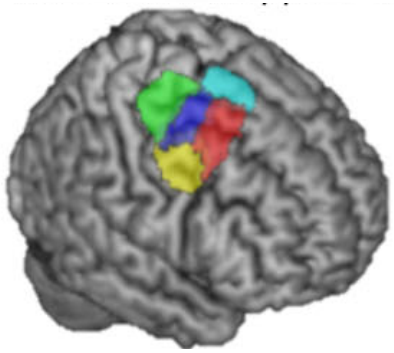
dmPFC: Eickhoff et al., *Cerebral Cortex 2015*



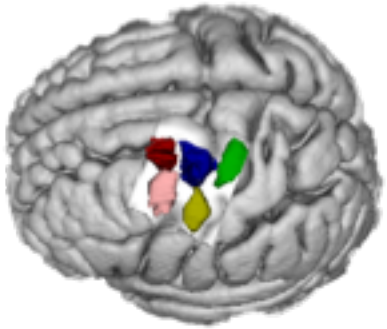
BA 44: Clos et al., *Neuroimage 2015*



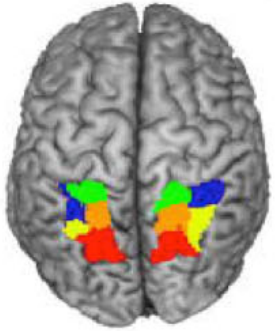
Pulvinar: Barron et al., *Hum Brain Mapp 2015*



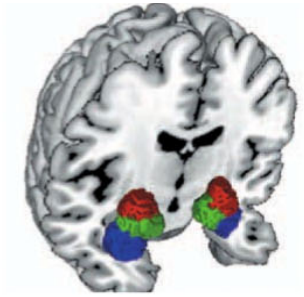
Right PMd: Genon et al., *Cerebral Cortex 2017*



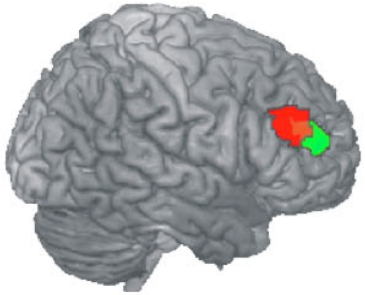
Left PMd: Genon et al., *NeuroImage 2018*



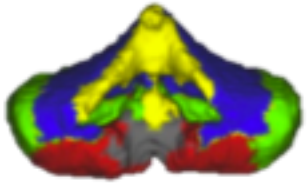
SPL: Wang et al., *Hum Brain Mapp 2015*



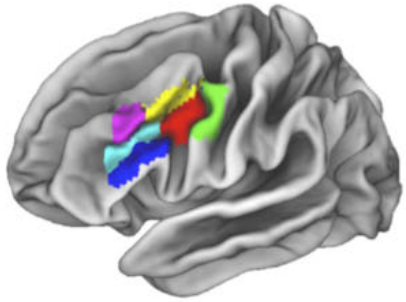
Amygdala: Bzdok et al., *Hum Brain Mapp 2013*



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



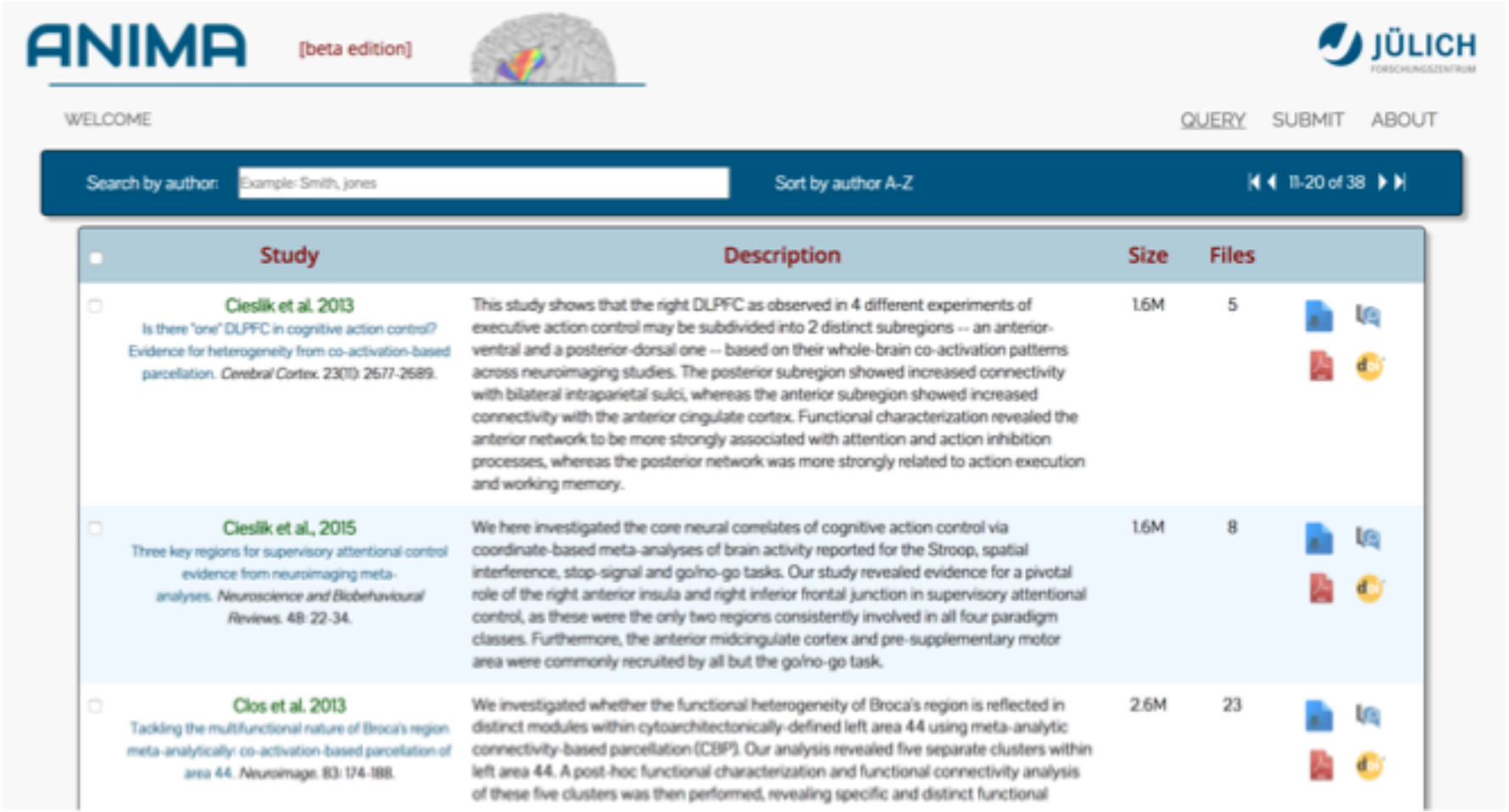
Cerebellum: Riedel et al., *NeuroImage 2015*



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

DATABASE FOR META-ANALYTICAL RESULTS

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



SUMMARY

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

References:

Eickhoff SB, Bzdok D, Laird AR, Roski C, Caspers S, Zilles K, Fox PT (2011). **Coactivation patterns distinguish cortical modules, their connectivity and functional differentiation**. Neuroimage 57, 938–949.

Eickhoff S, Yeo T, Genon S. **Imaging-based parcellations of the human brain**. Nat Rev Neurosci. In press.

Genon S, Li H, Fan L, Müller VI, Cieslik EC, Hoffstaedter F, Reid AT, Langer R, Grefkes, C, Fox PT, Moebus S, Caspers S, Amunts K, Jiang T, Eickhoff SB (2017). **The Right Dorsal Premotor Mosaic: Organization, Functions, and Connectivity**. Cereb. Cortex, 27(3), 2095-2110.

Toro R, Fox PT, Paus T (2008). **Functional coactivation map of the human brain**. Cereb. Cortex, 18, 2553–2559.

THANK YOU

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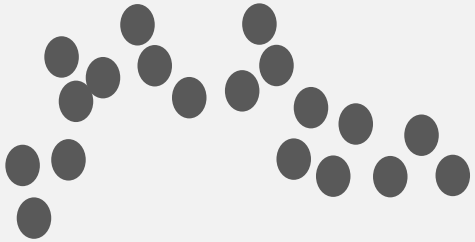
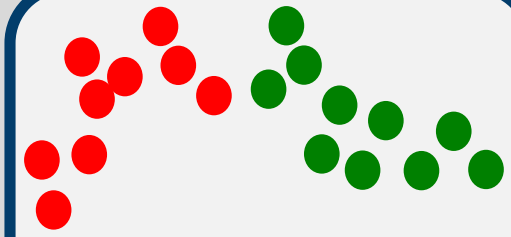
CBP: HOW MANY CLUSTERS ?

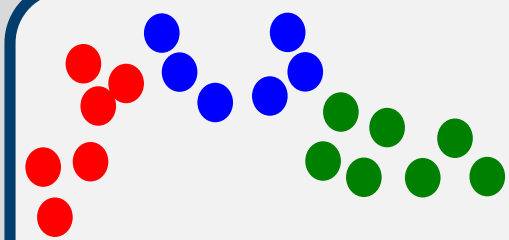
How many clusters?

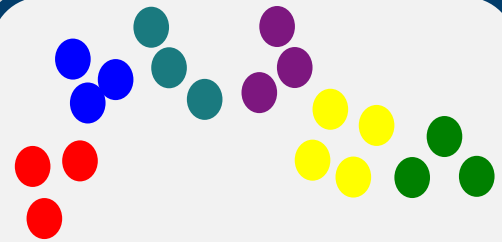


➔ Search for several k:

e.g.: 2 -> 8





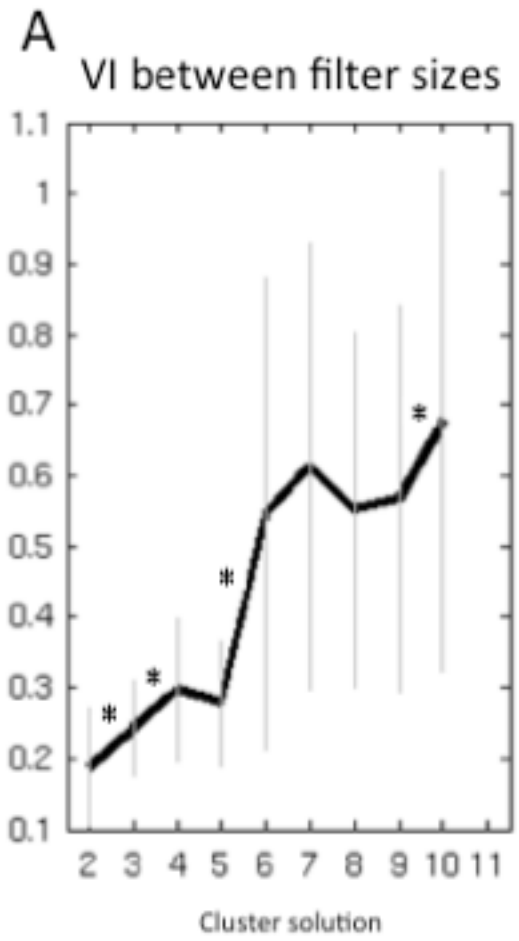


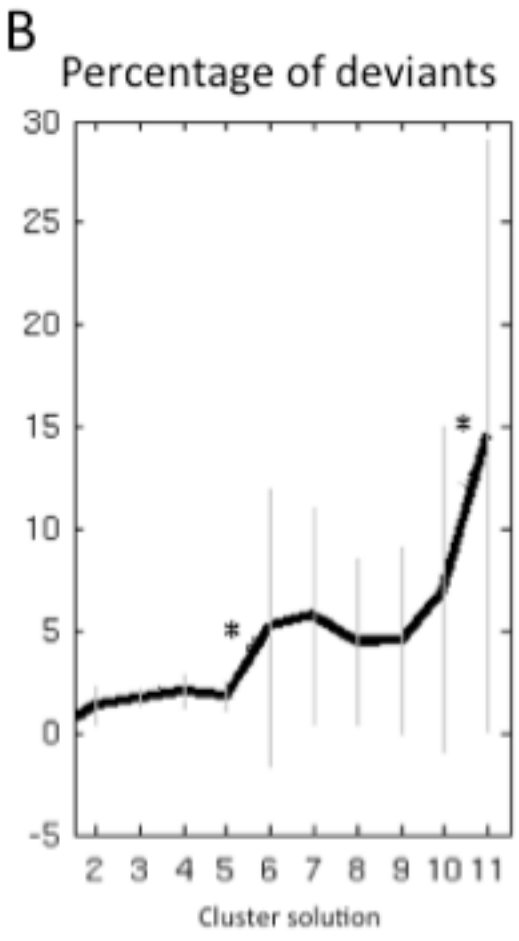
CBP: HOW MANY CLUSTERS ?

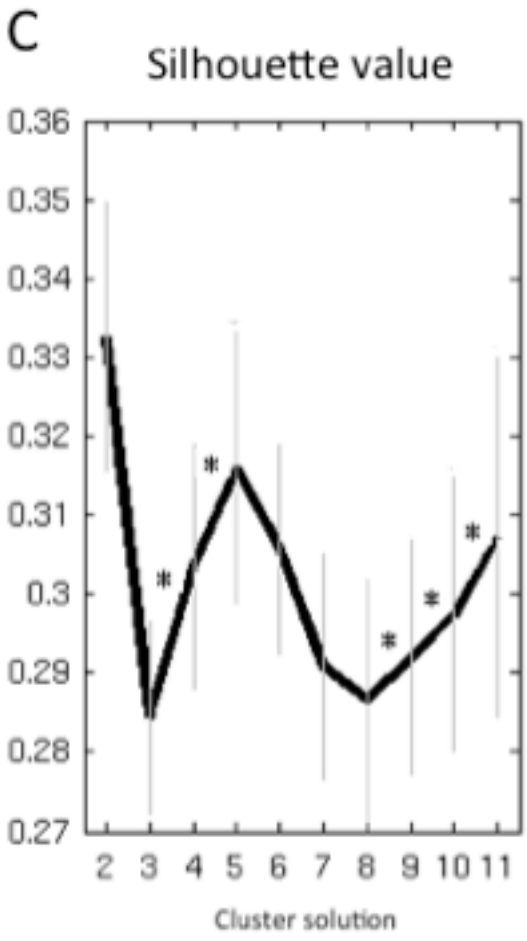
Information theory

consistency

separation







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