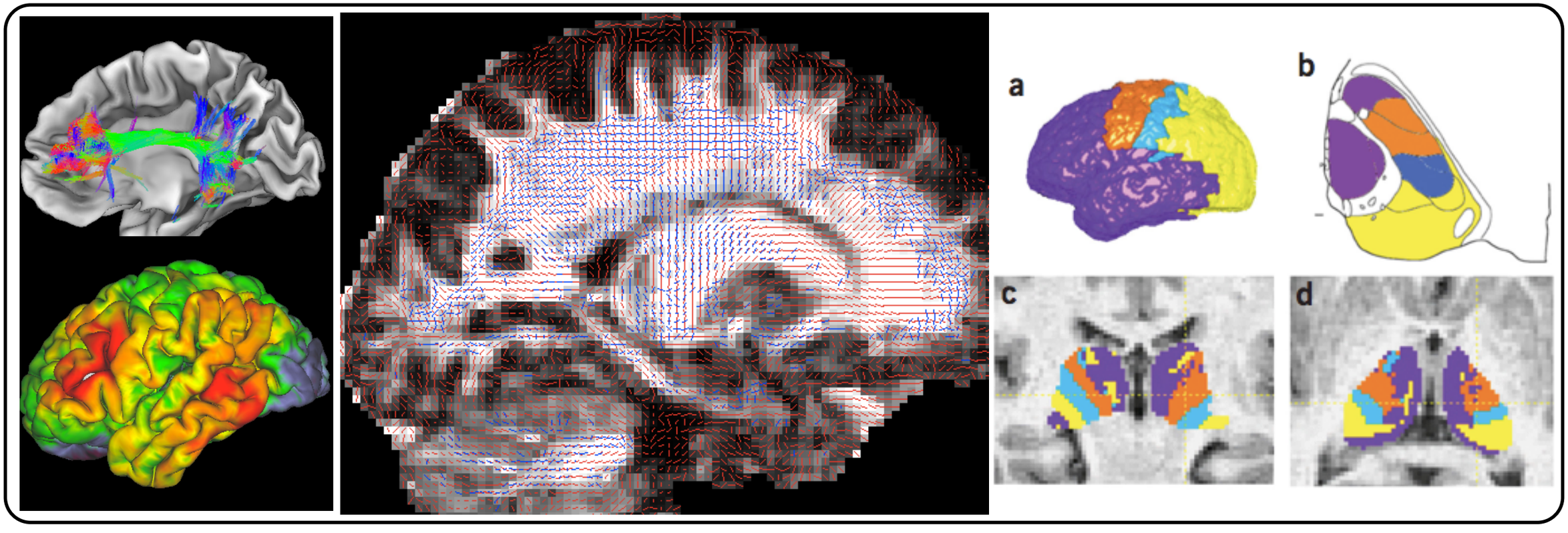
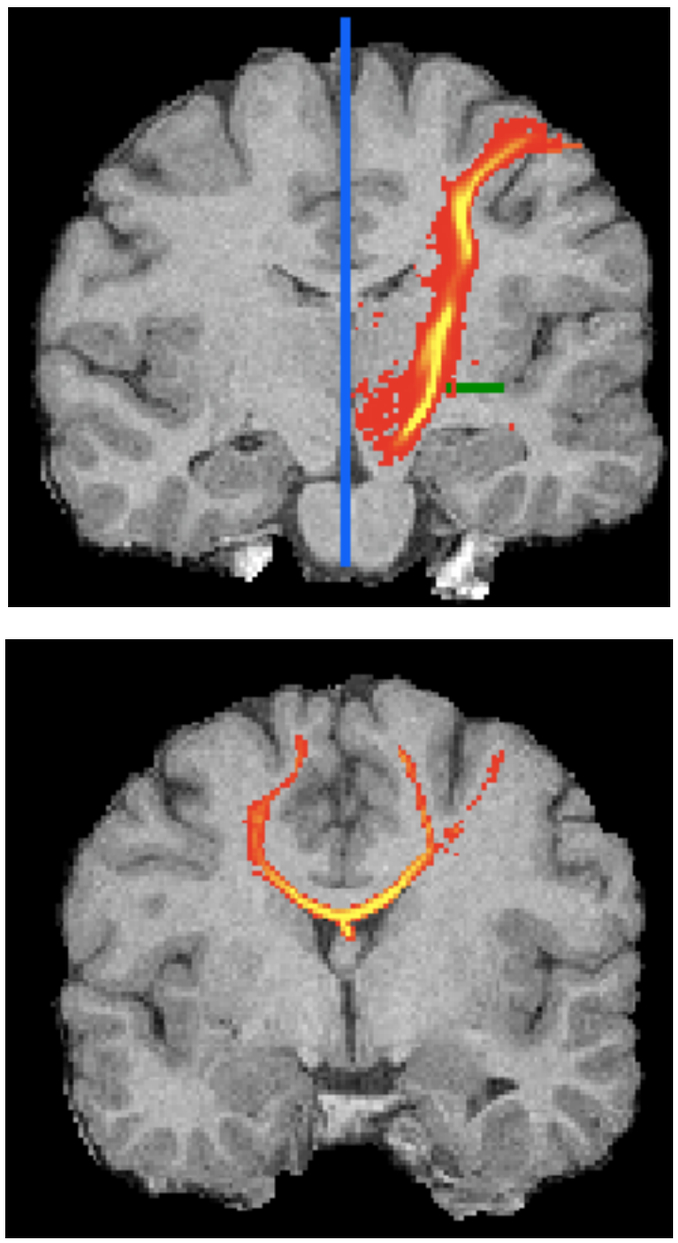
Diffusion Tractography

- Goal of tractography
- Estimating Fibre Orientations - BEDPOSTX
- Probabilistic Tractography - PROBTRACKX
- ProbtrackX outputs
- Tractography limitations



ProbtrackX outputs

Known white matter tracts

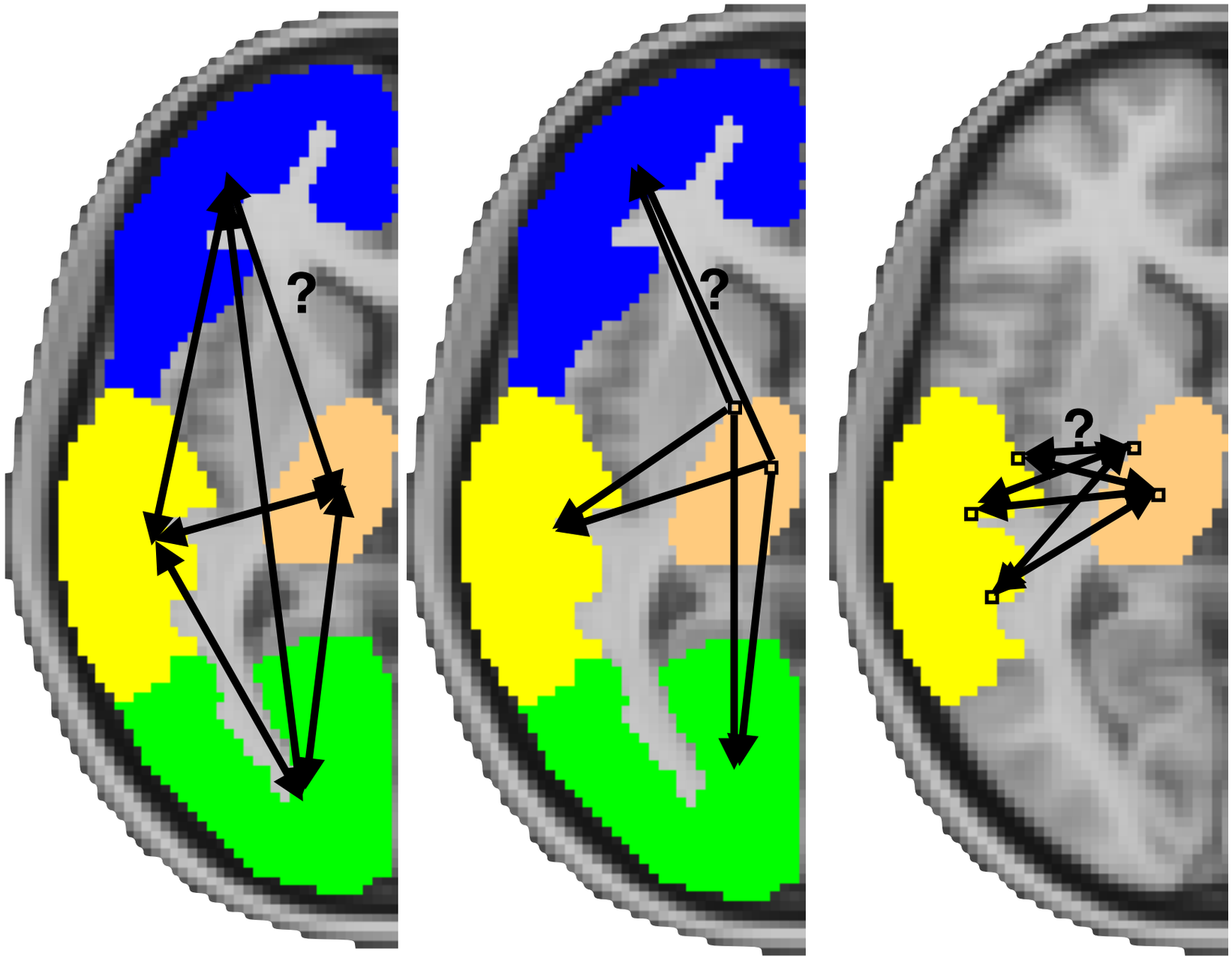


Connectivity matrices

ROI by ROI

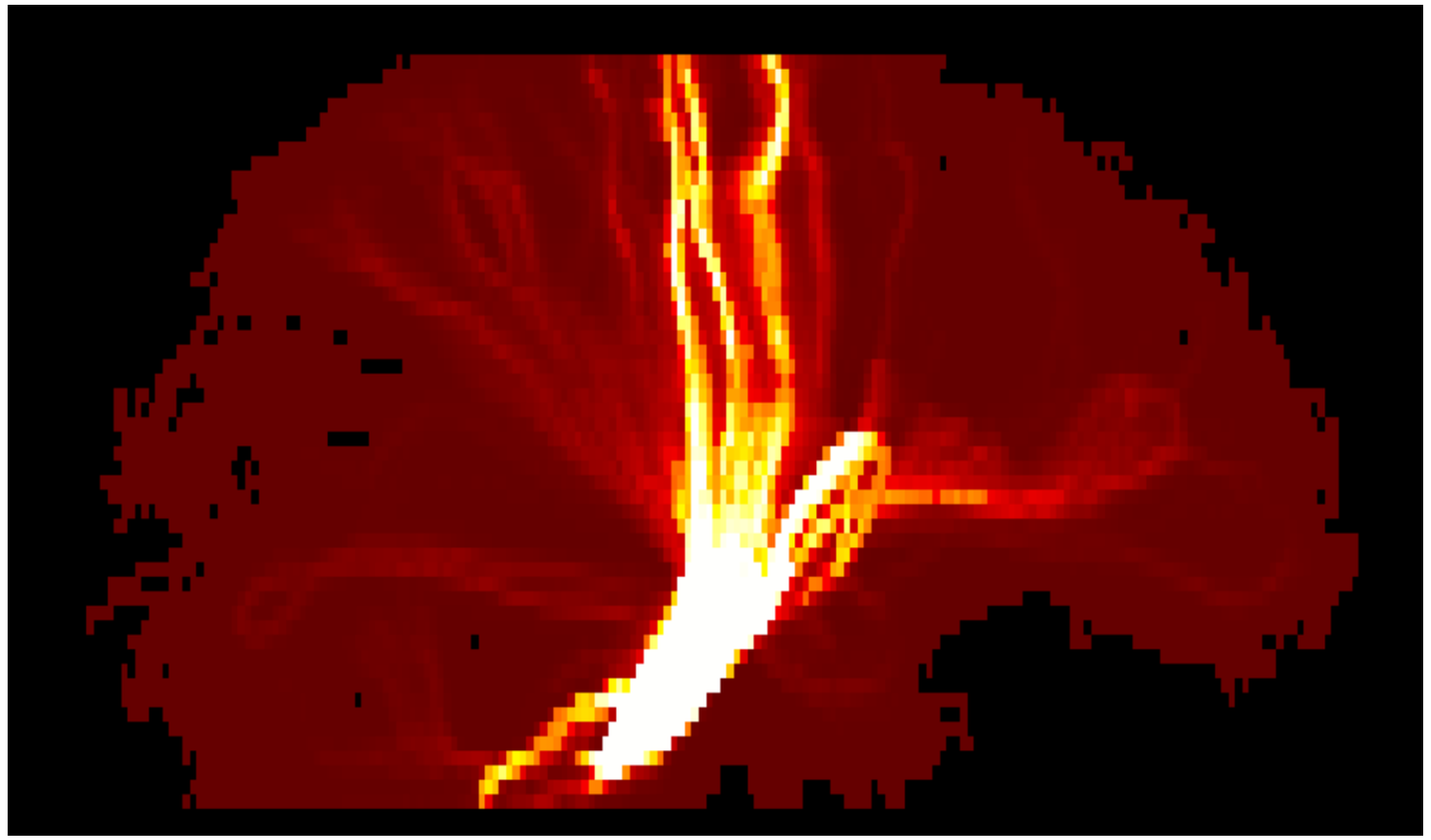
voxel by ROI

voxel by voxel



Adding Prior Knowledge to Tractography

- Because of the uncertainty propagation, the spatial distribution of paths is often very wide.

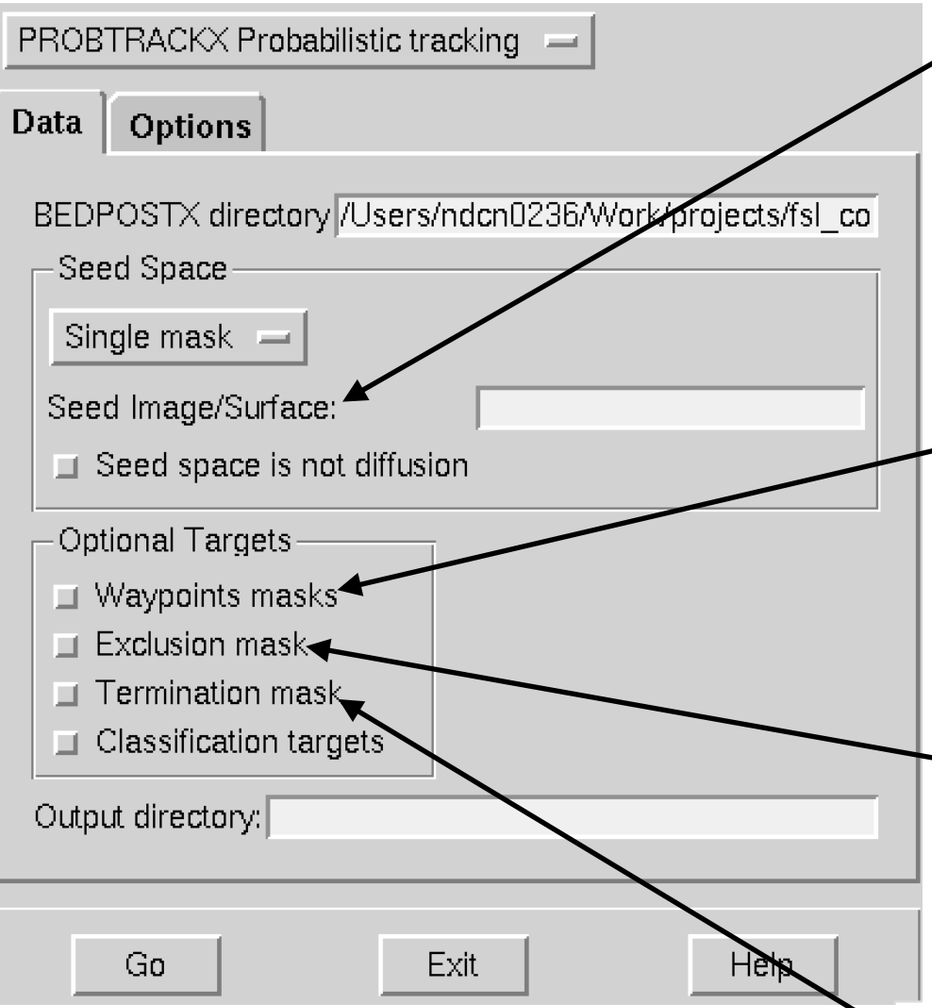


Low Probability

High Probability

Adding Prior Knowledge to Tractography

Fdt GUI:



- Once a seed is specified, prior anatomical knowledge can be imposed to assist the dissection of a specific tract.

- **Waypoint** ROIs
  If a curve does not go through, it is discarded.

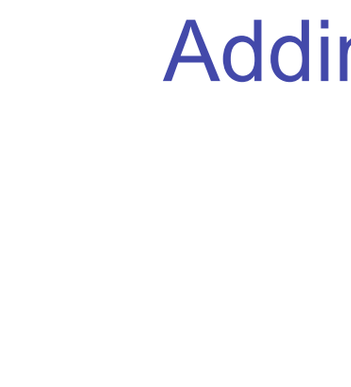
- **Exclusion** ROI
  If a curve goes through, it is discarded.

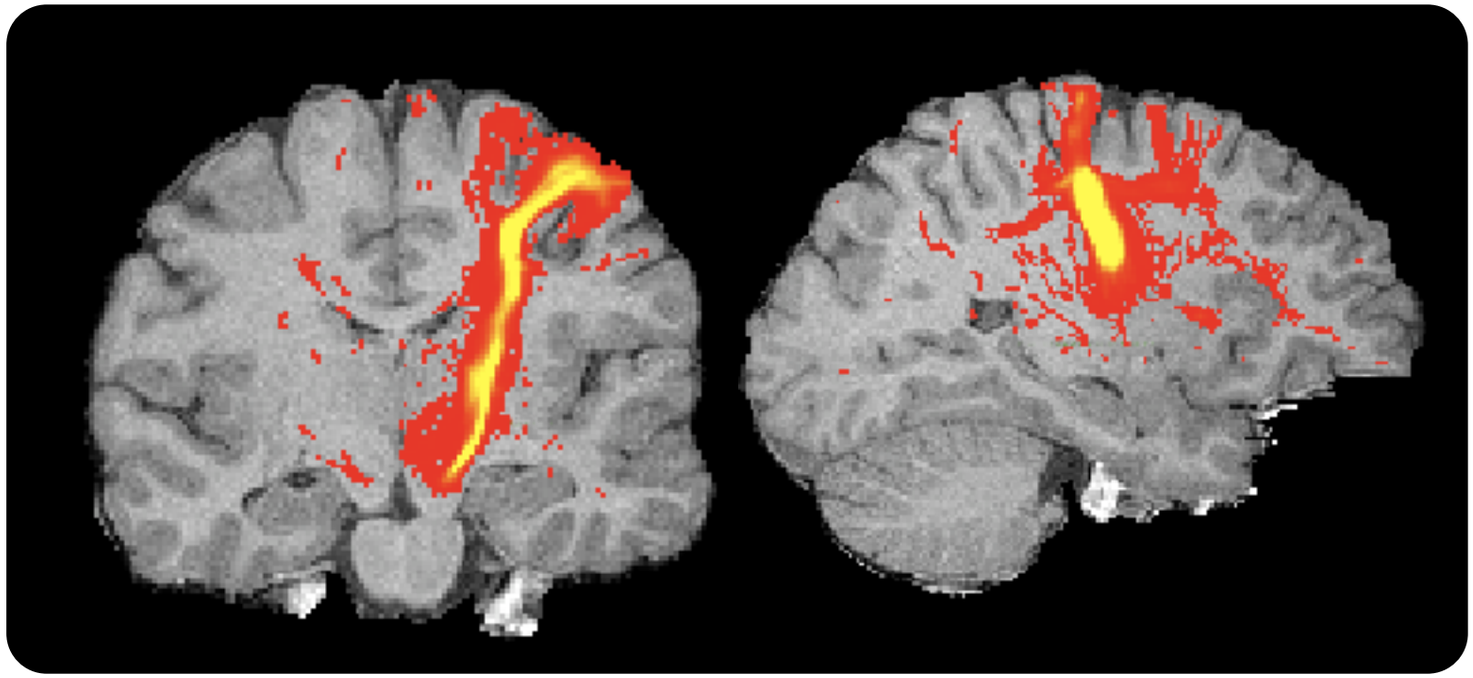
- **Termination** ROI
  If a curve goes through, it is terminated.

Adding Prior Knowledge to Tractography

Cortico-spinal tract

Seed: M1, hand area



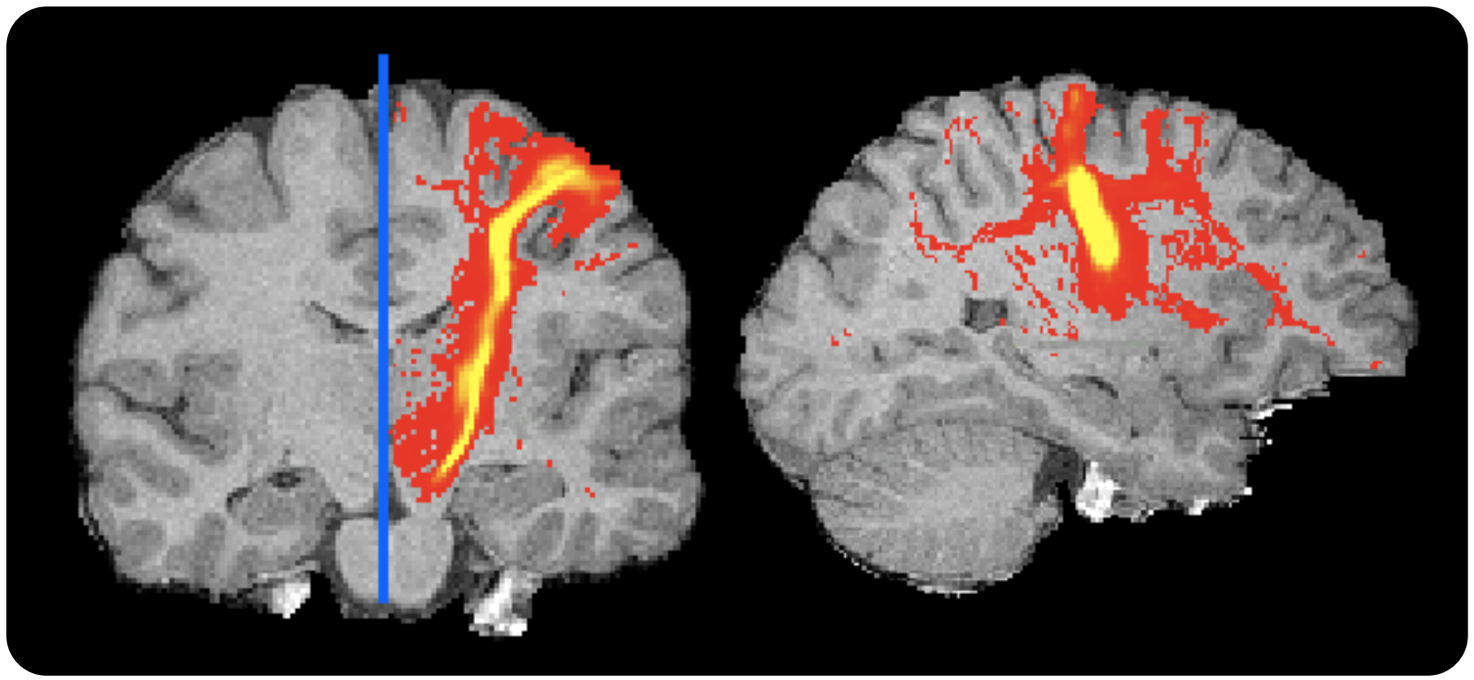


No ROIs

Adding Prior Knowledge to Tractography

Cortico-spinal tract

Seed: M1, hand area

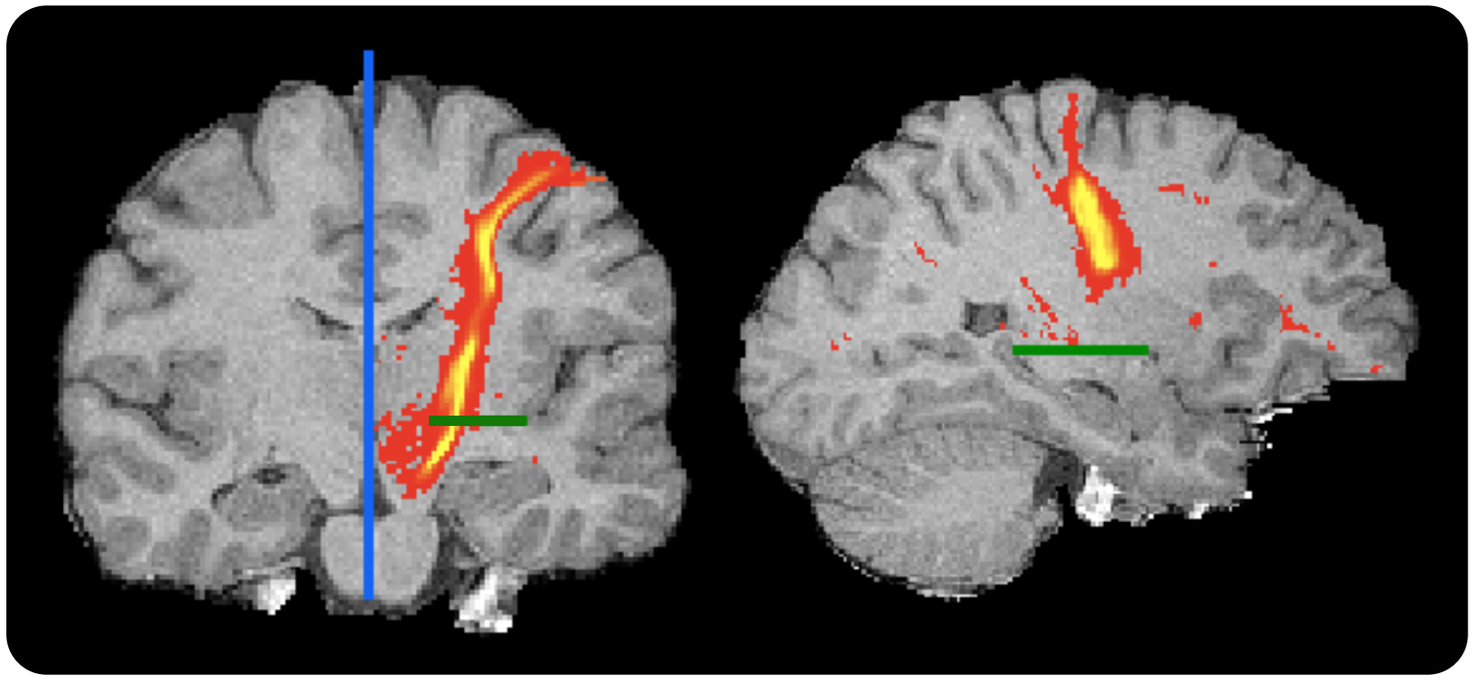


Exclusion: Mid-Sagittal plane

Adding Prior Knowledge to Tractography

Cortico-spinal tract

Seed: M1, hand area

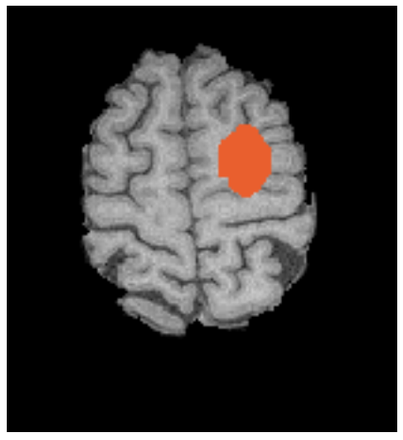


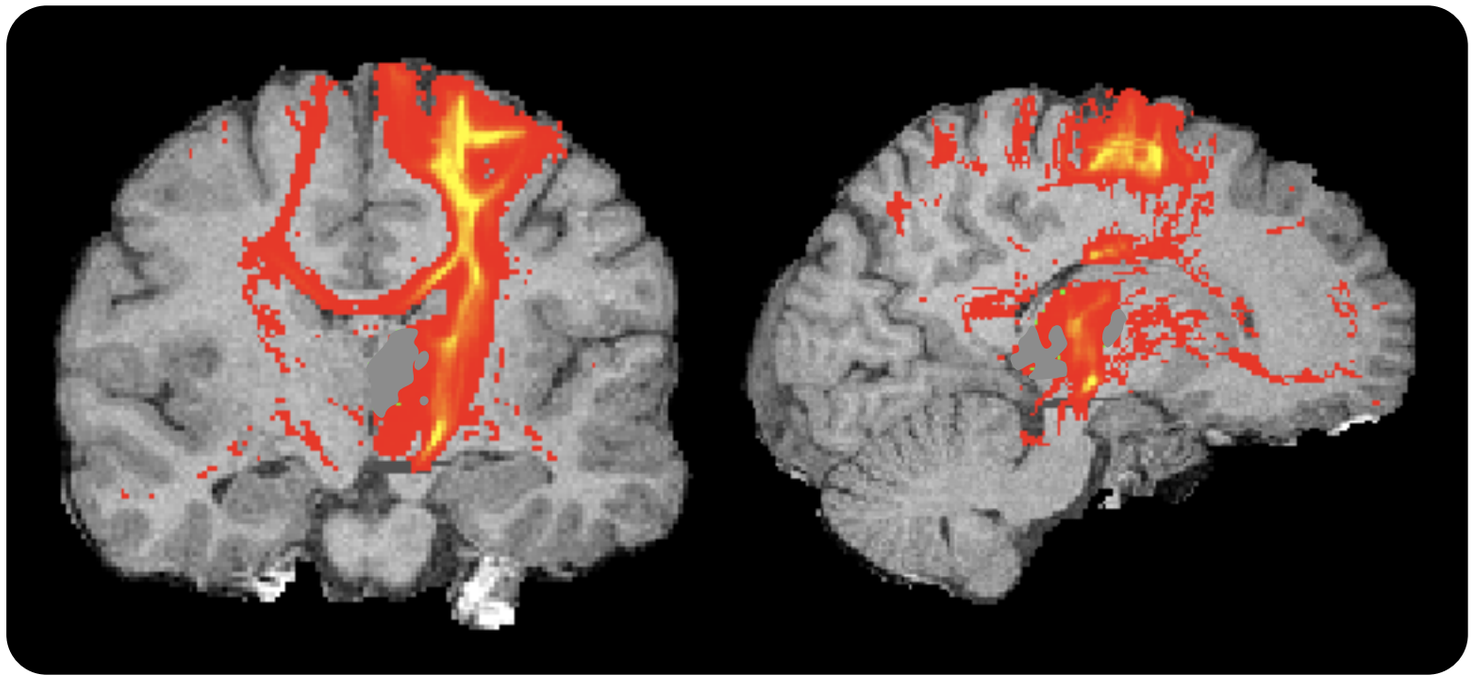
Waypoint: Internal Capsule

Adding Prior Knowledge to Tractography

Corpus Callosum

Seed: dorsal PMC



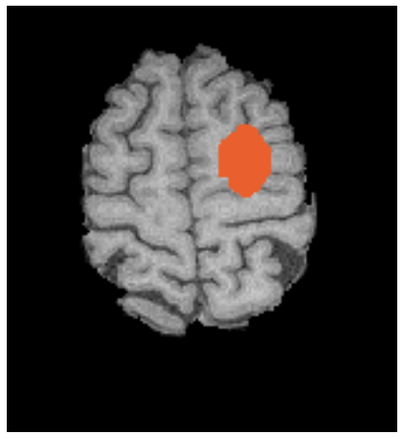


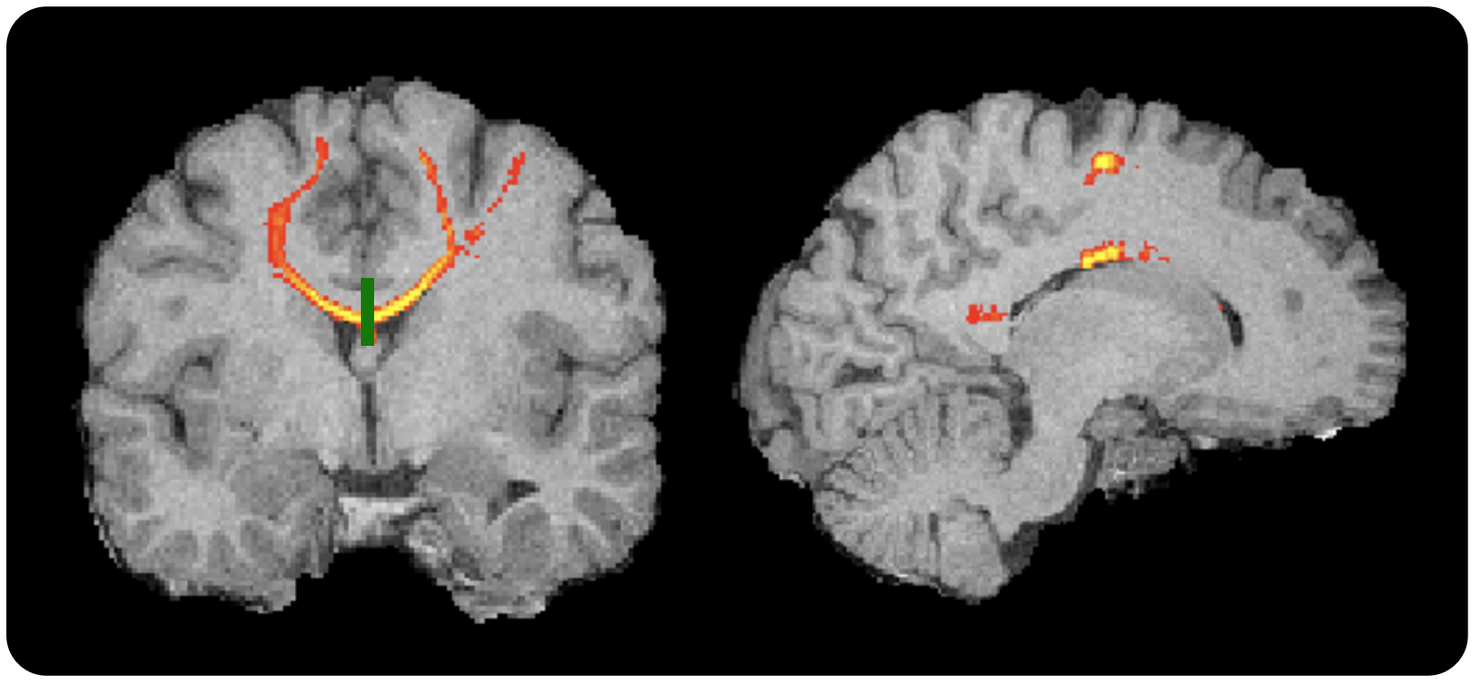
No ROIs

Adding Prior Knowledge to Tractography

Corpus Callosum

Seed: dorsal PMC

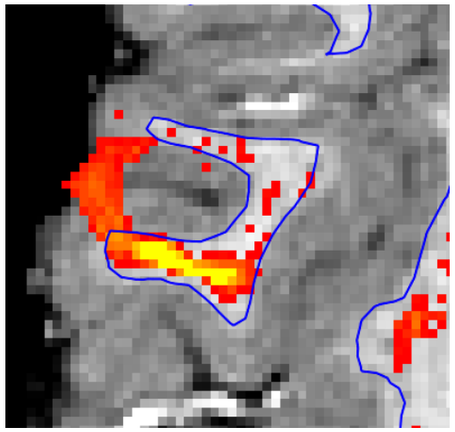




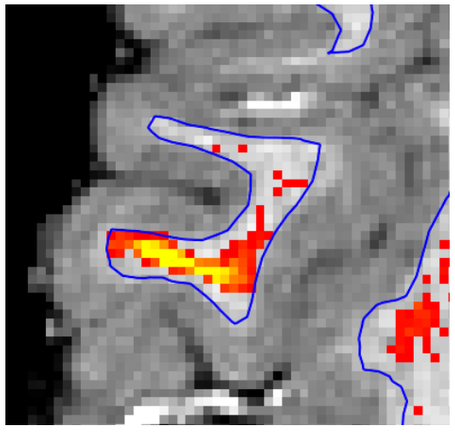
Waypoint: Corpus Callosum

Surfaces as constraints

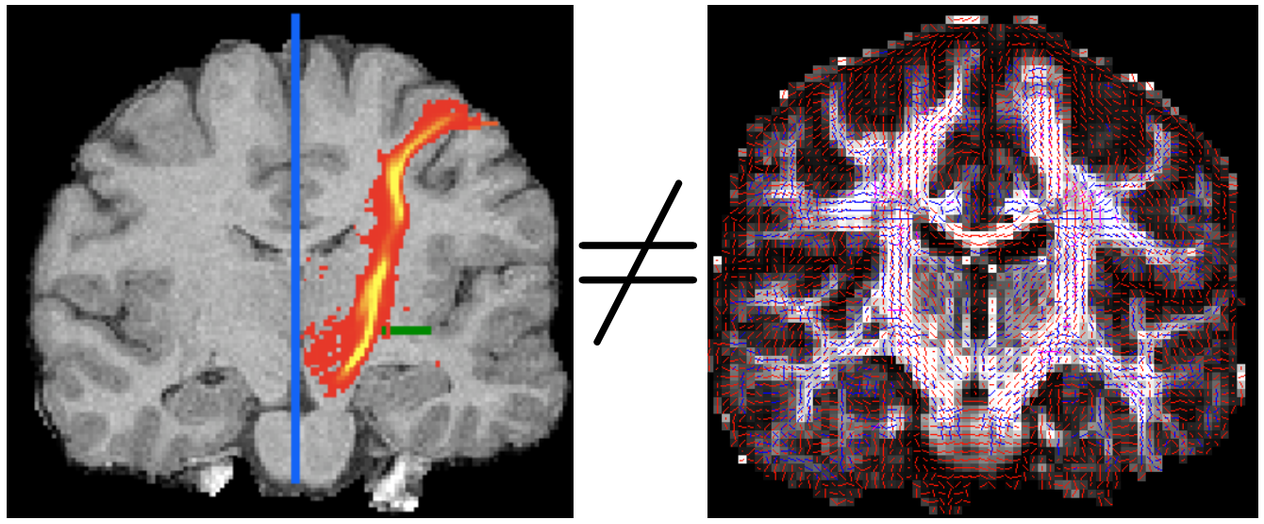
No surface constraint



Surface as termination mask

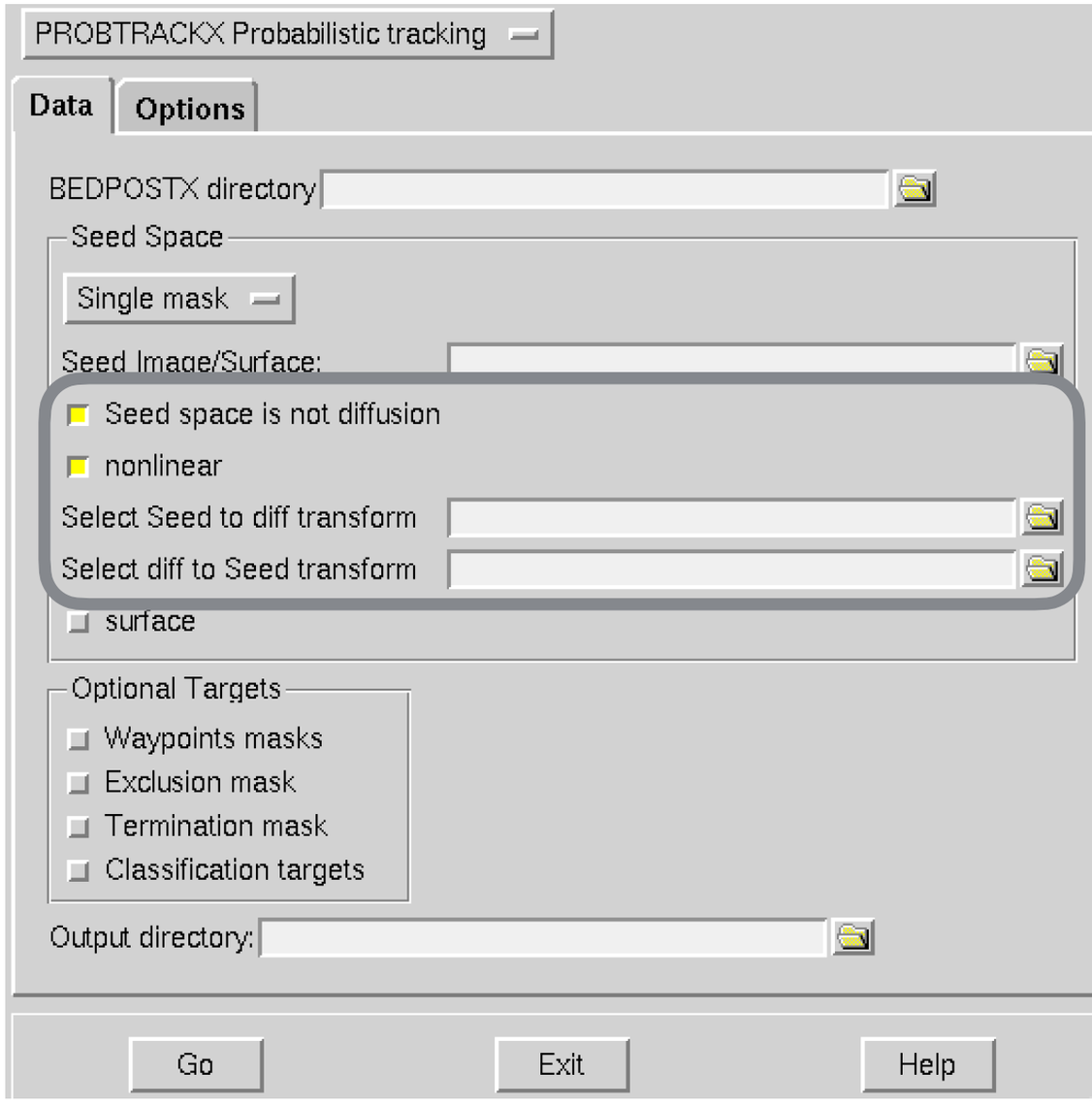


How to use masks in standard space?

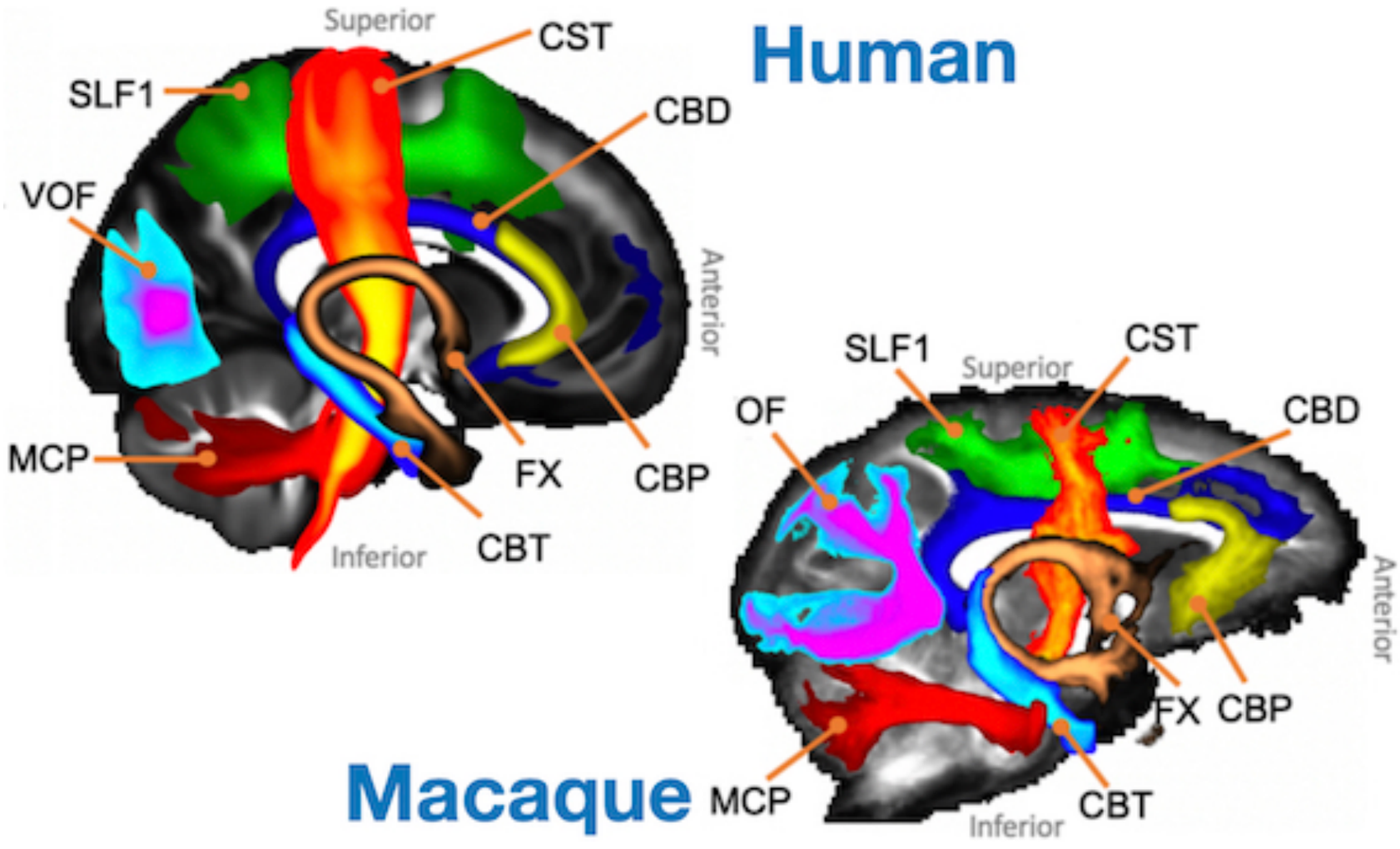


- Register to standard space
  - b0 or FA -> T1w -> standard T1w
  - FA -> standard FA
- **Don't** transform masks -> diffusion space
- **Don't** transform diffusion -> standard space

Tell probtrackX about transform:



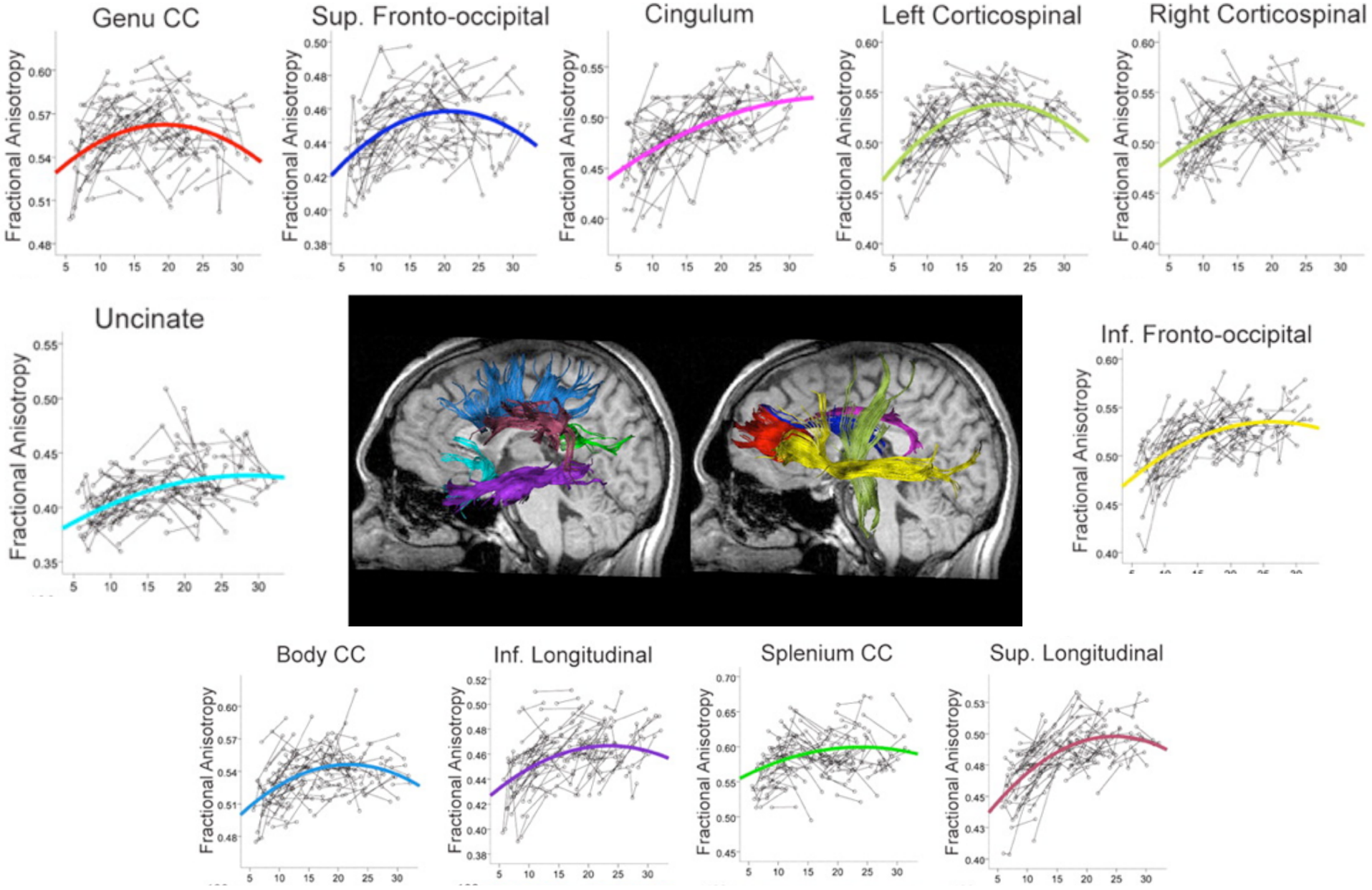
Xtract: generating tracts for you



https://fsl.fmrib.ox.ac.uk/fsl/fslwiki/XTRACT

Connectivity - Why do we care?

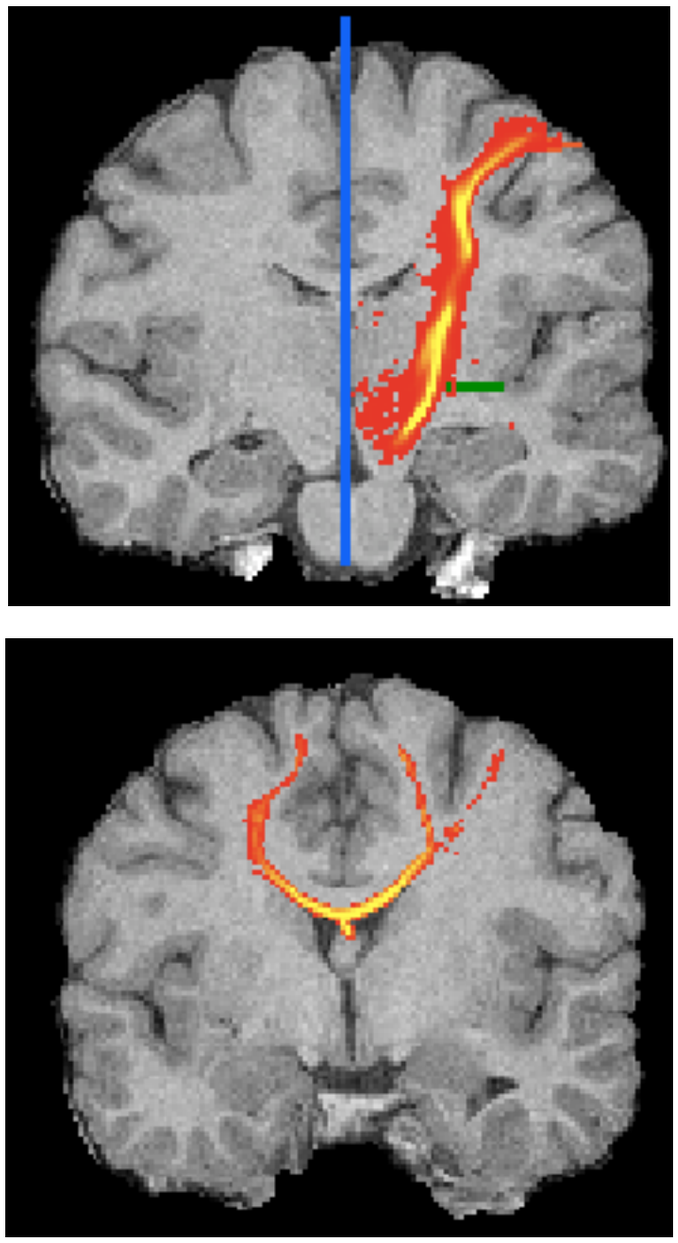
- Tractography provides non-invasive localisation and semi-quantitative biomarkers



Lebel, Beaulieu J Neuroscience 2011

ProbtrackX outputs

Known white matter tracts

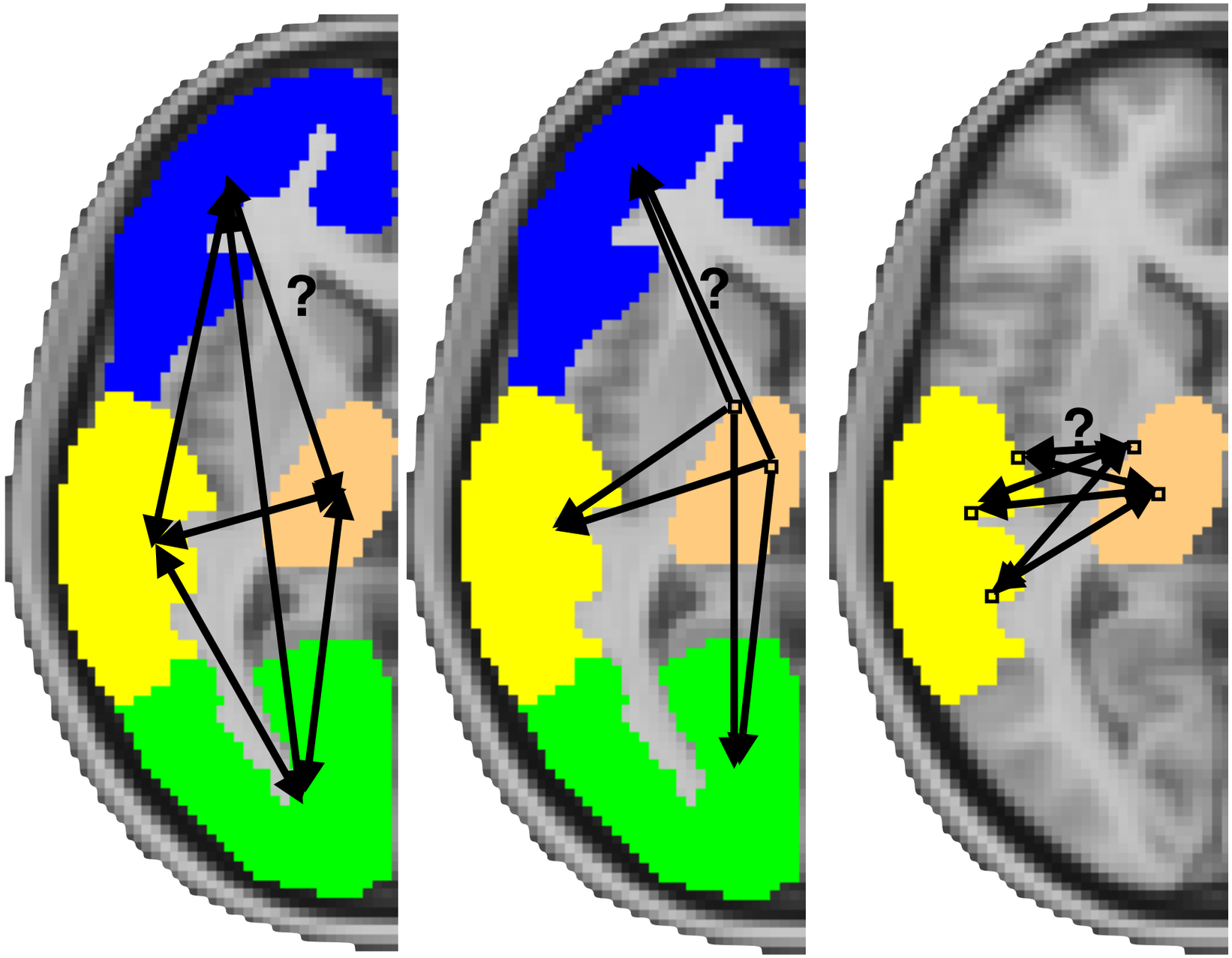


Connectivity matrices

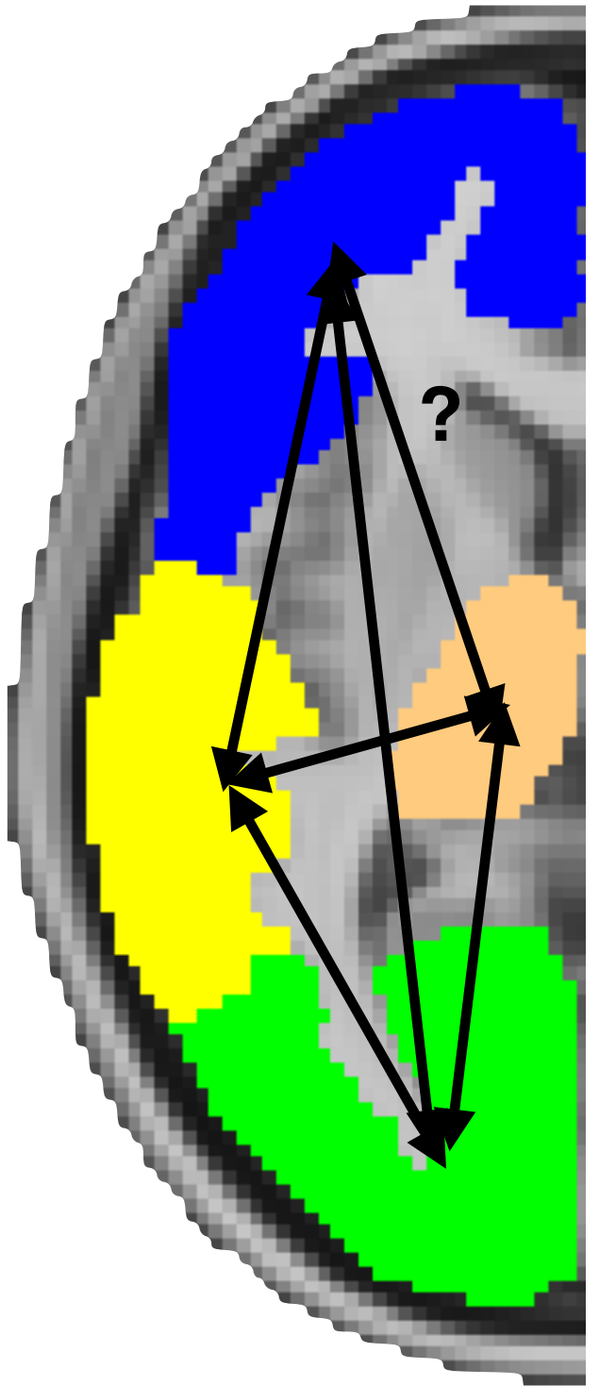
ROI by ROI

voxel by ROI

voxel by voxel



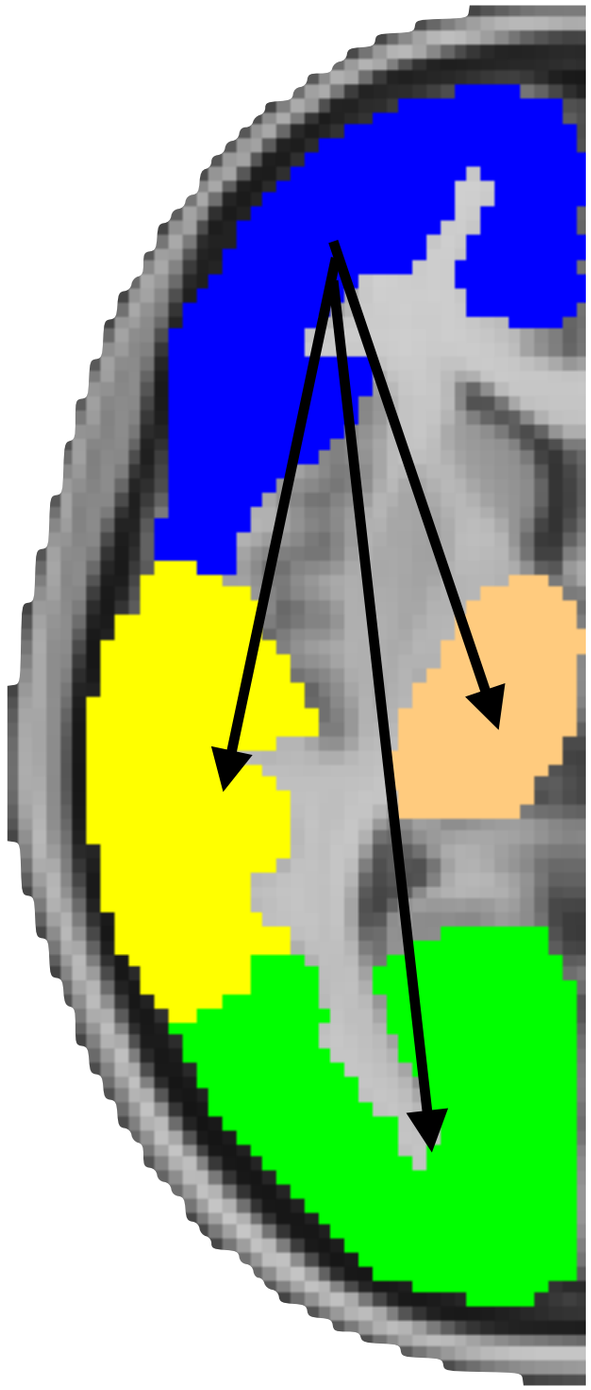
Connectivity between ROIs



Resulting matrix:

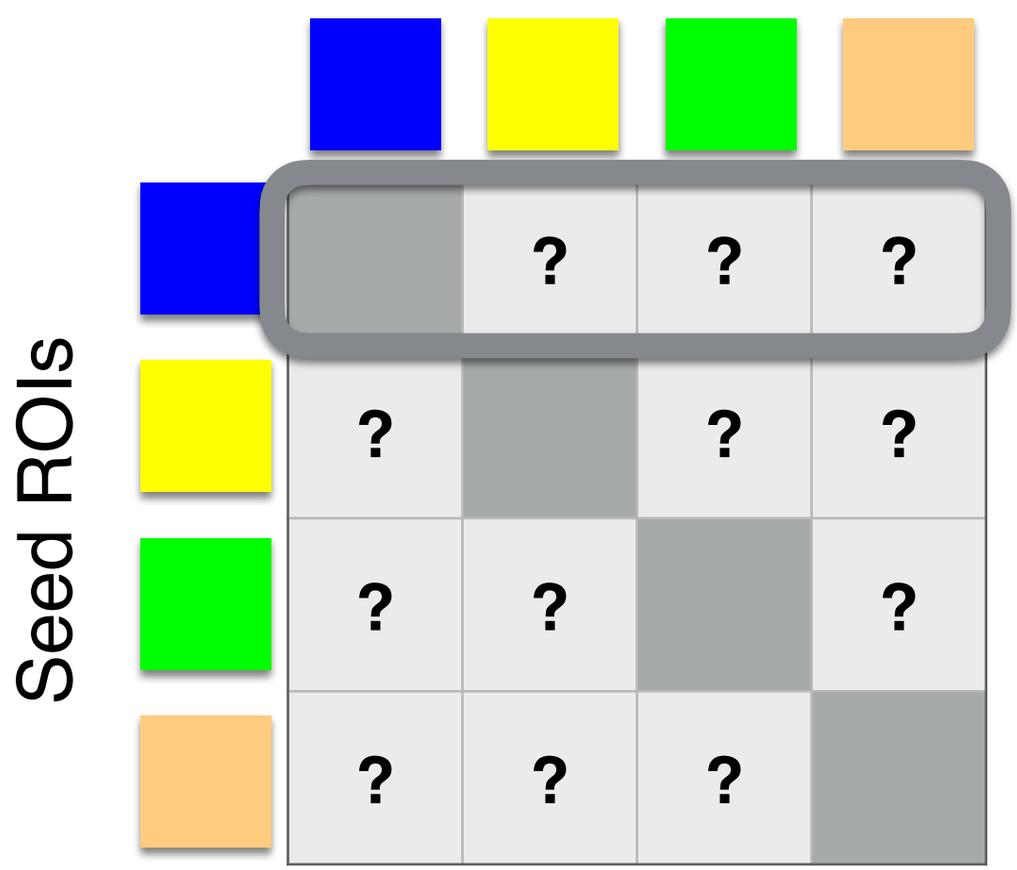
		?	?	?
	?		?	?
	?	?		?
	?	?	?	

Connectivity between ROIs

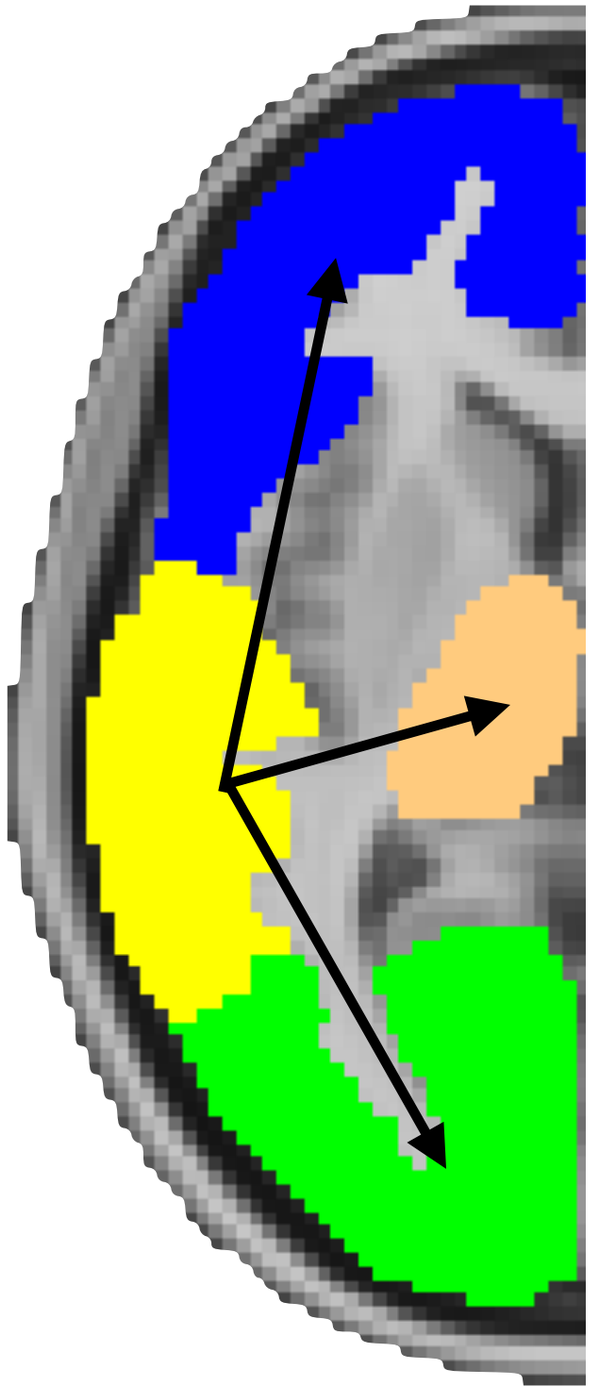


- Seed from blue
- Other ROIs are waypoints
- Fill first row of matrix

Resulting matrix:

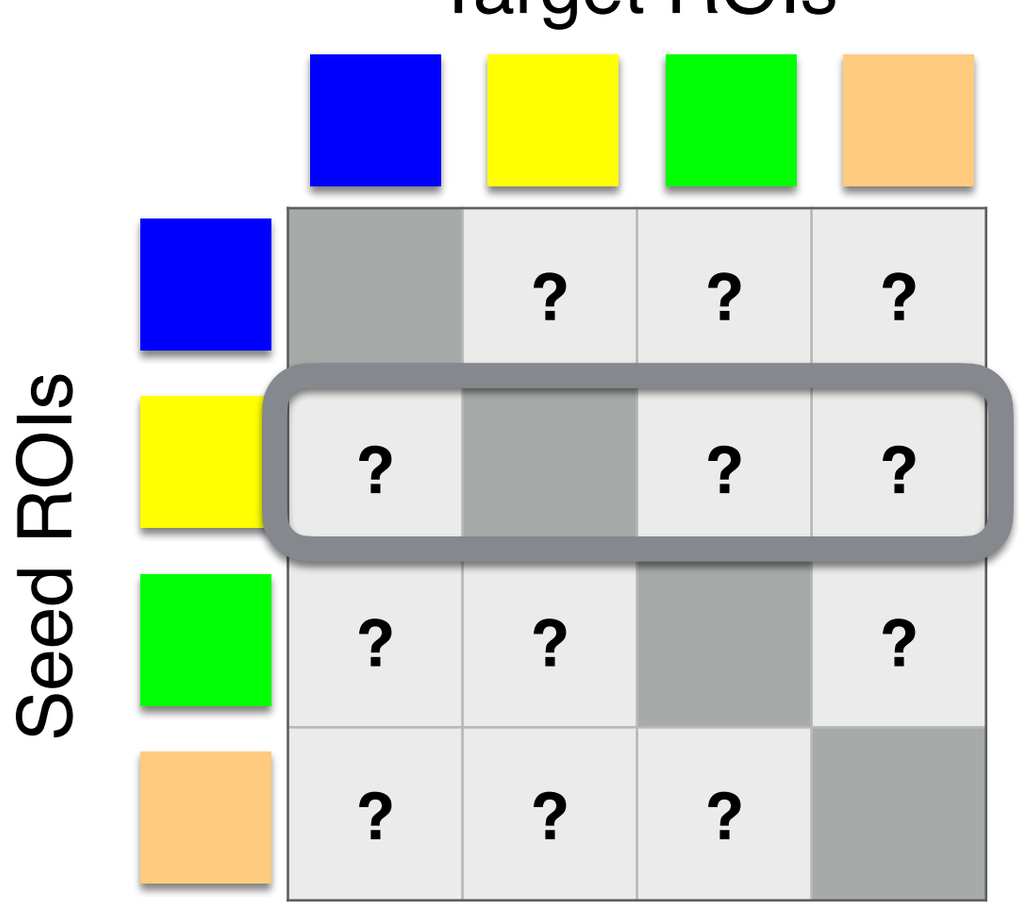


Connectivity between ROIs

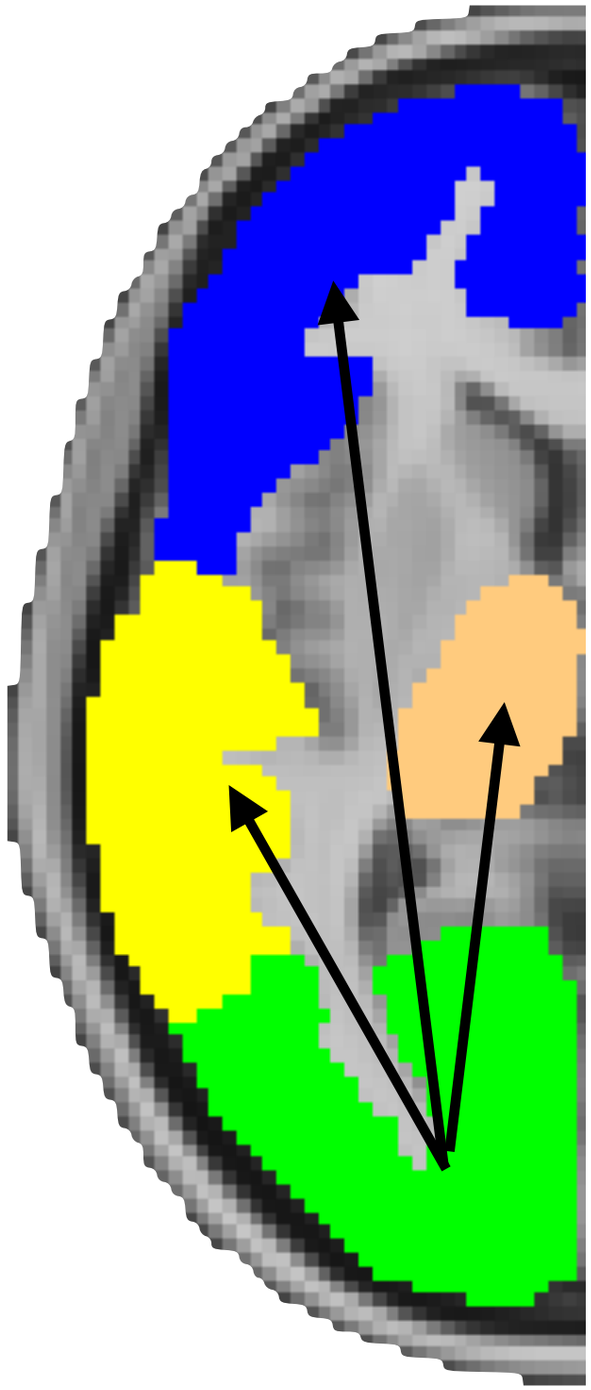


- Seed from yellow
- Other ROIs are waypoints
- Fill first row of matrix

Resulting matrix:



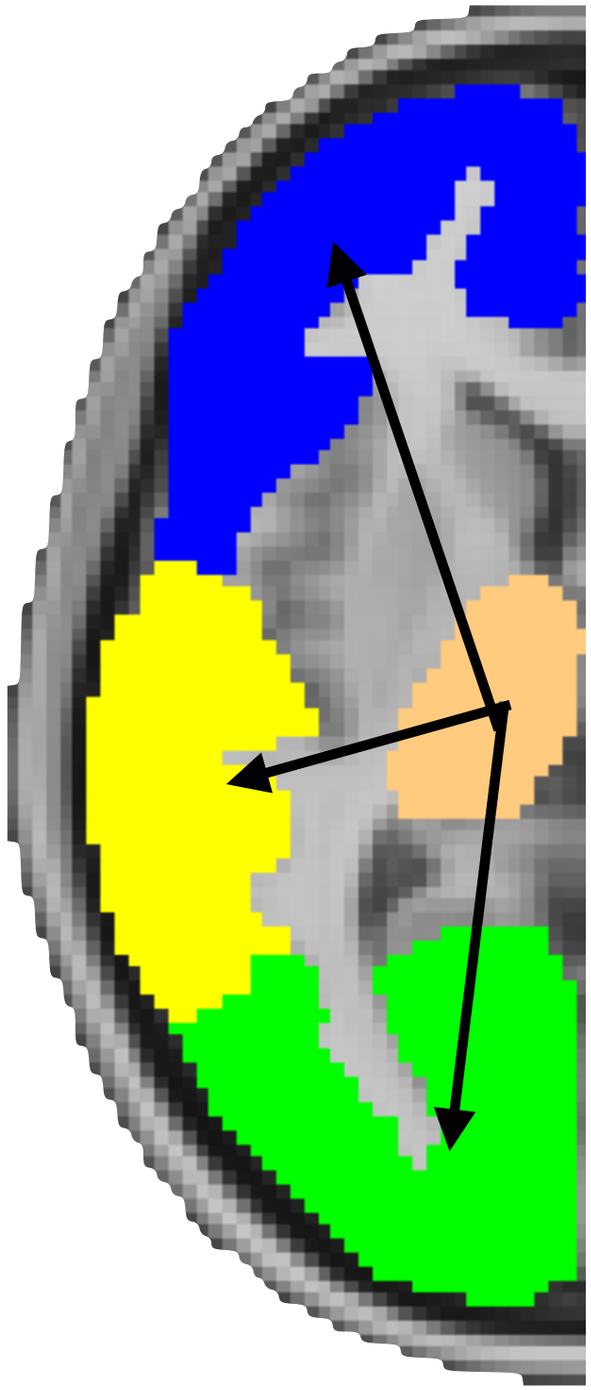
Connectivity between ROIs



- Seed from green
- Other ROIs are waypoints
- Fill first row of matrix

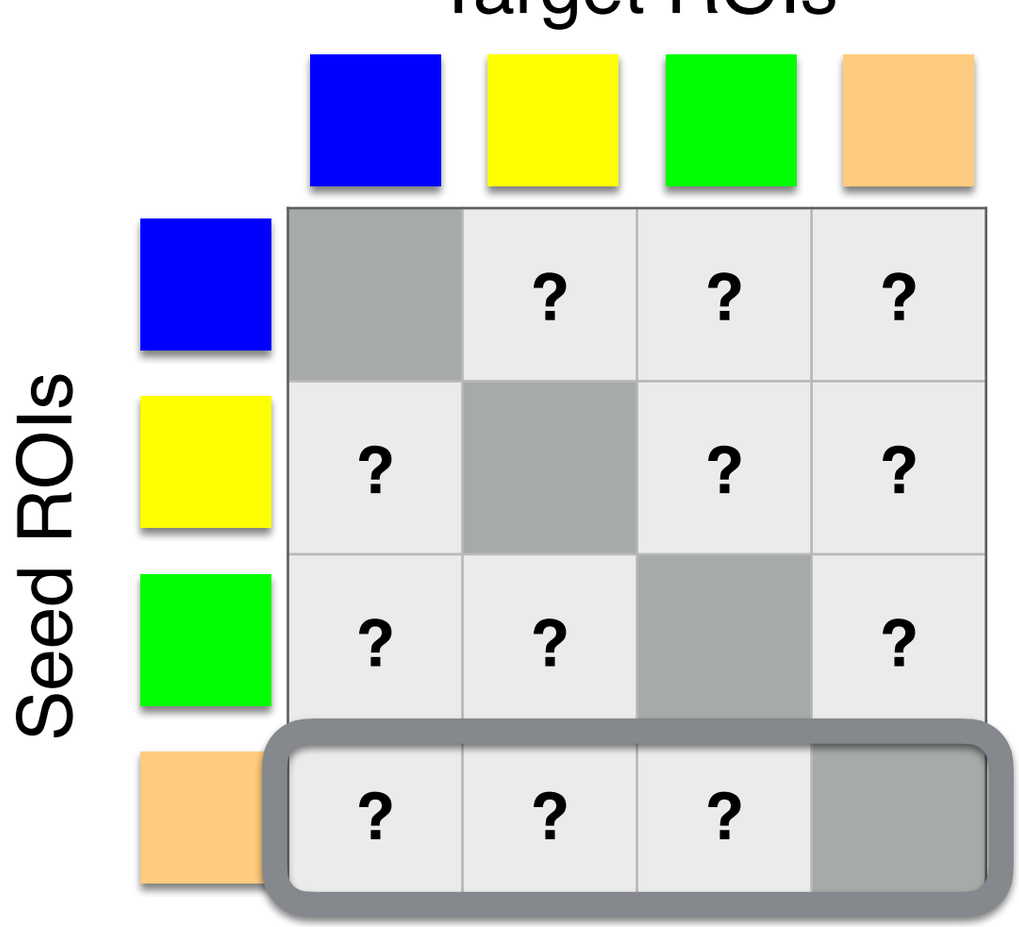
Resulting matrix:

Connectivity between ROIs

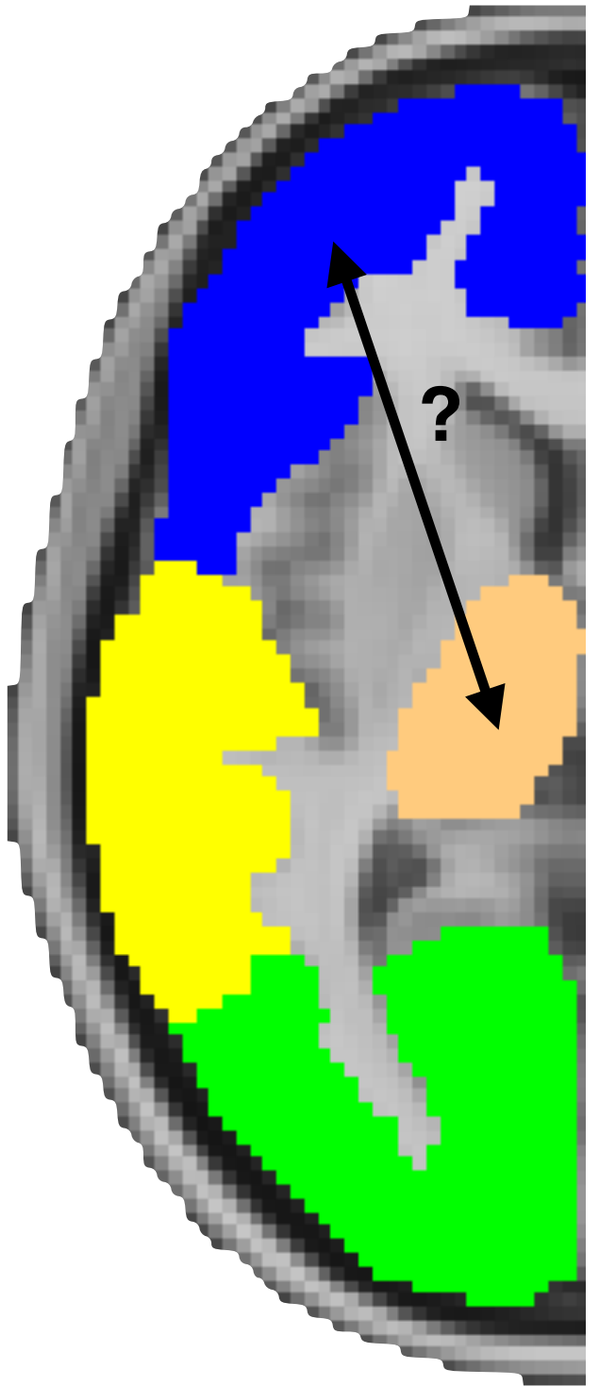


- Seed from copper
- Other ROIs are waypoints
- Fill first row of matrix

Resulting matrix:

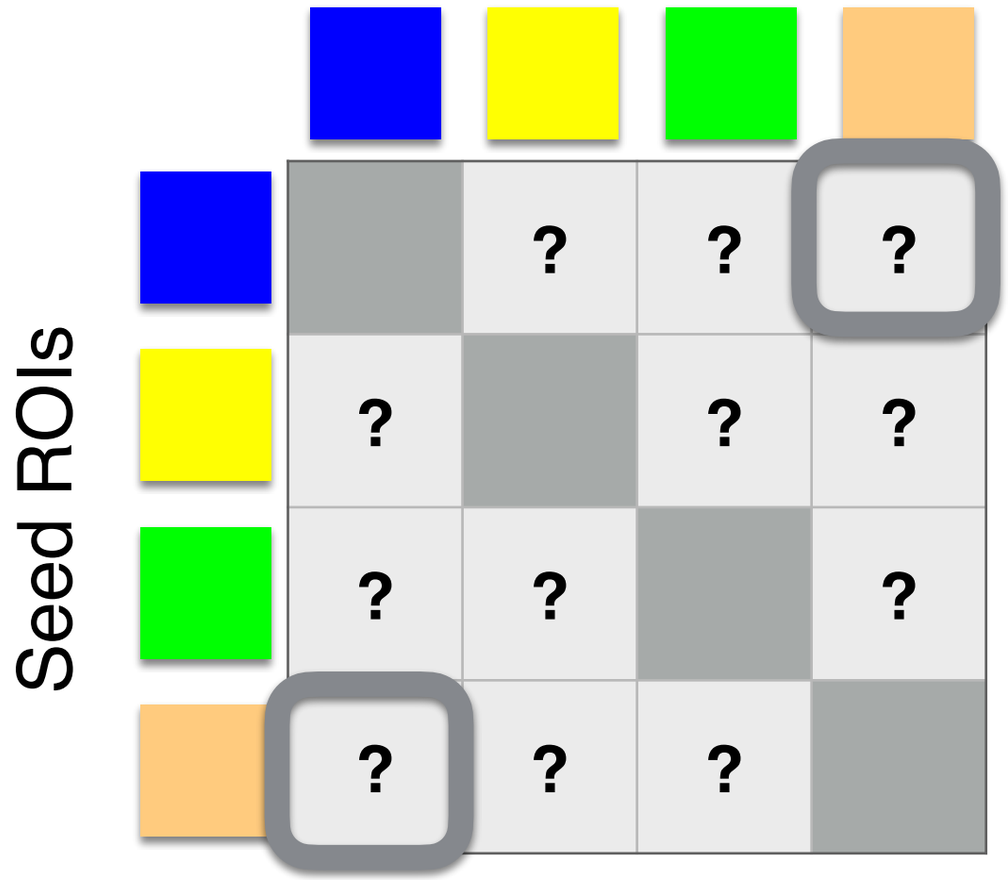


Connectivity between ROIs

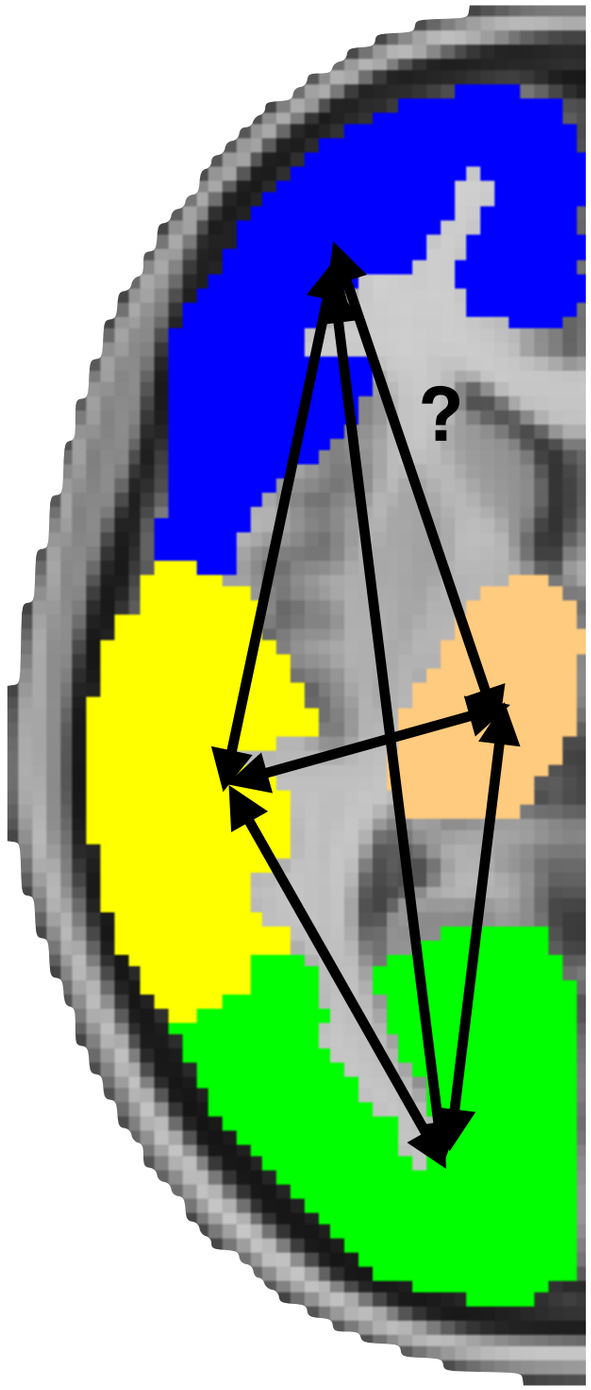


$$P(\blacksquare \leftrightarrow \blacksquare) = (P(\blacksquare \leftarrow \blacksquare) + P(\blacksquare \rightarrow \blacksquare))\,/2$$

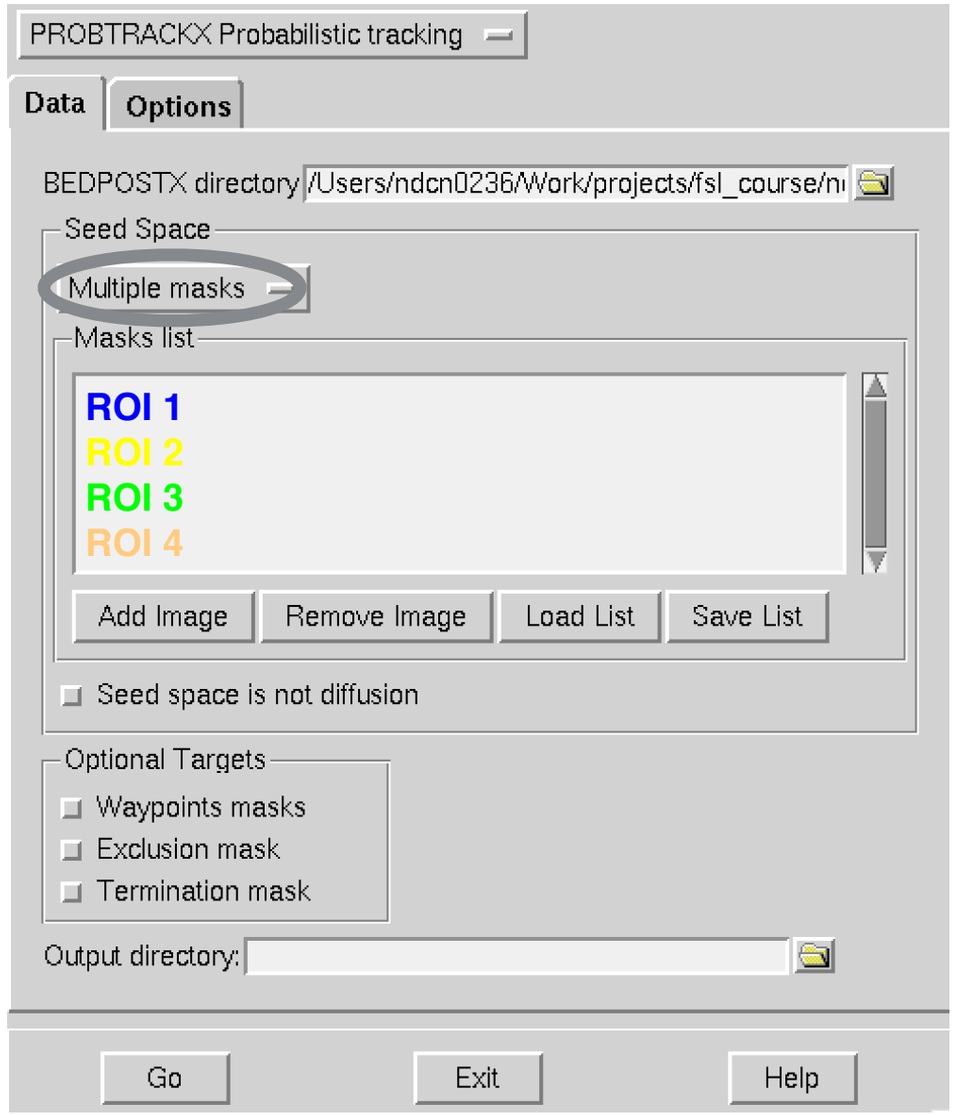
Resulting matrix:



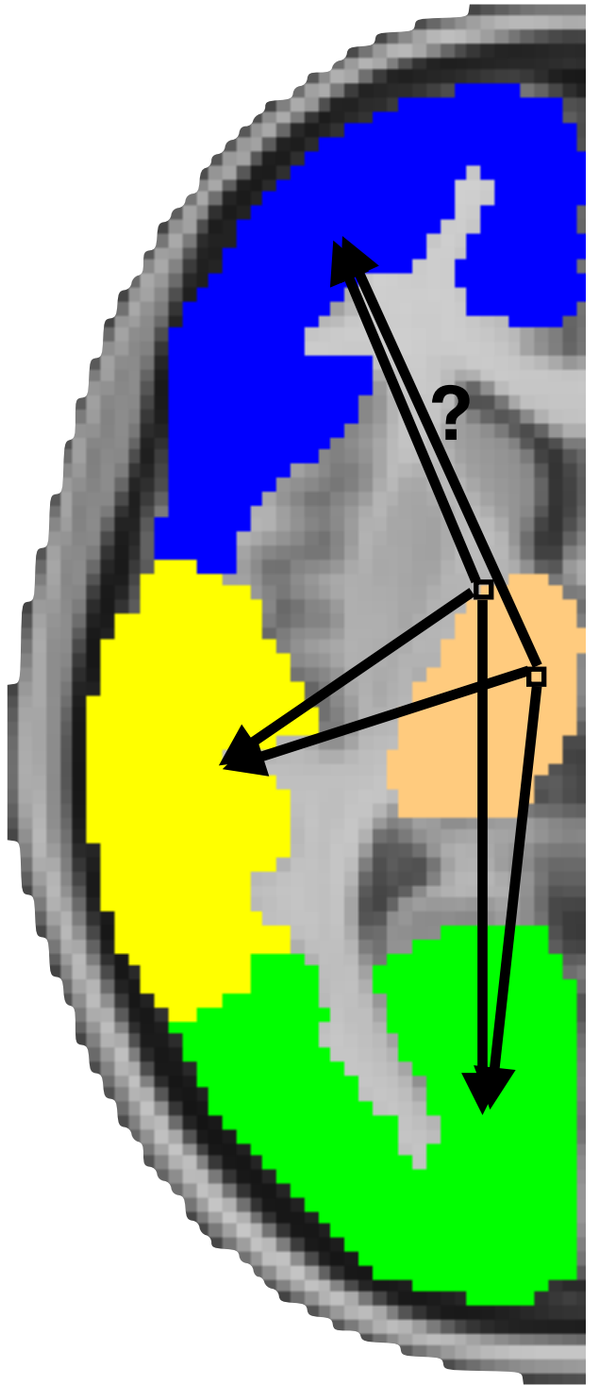
Connectivity between ROIs



Fdt GUI:



Connectivity between voxels and ROIs



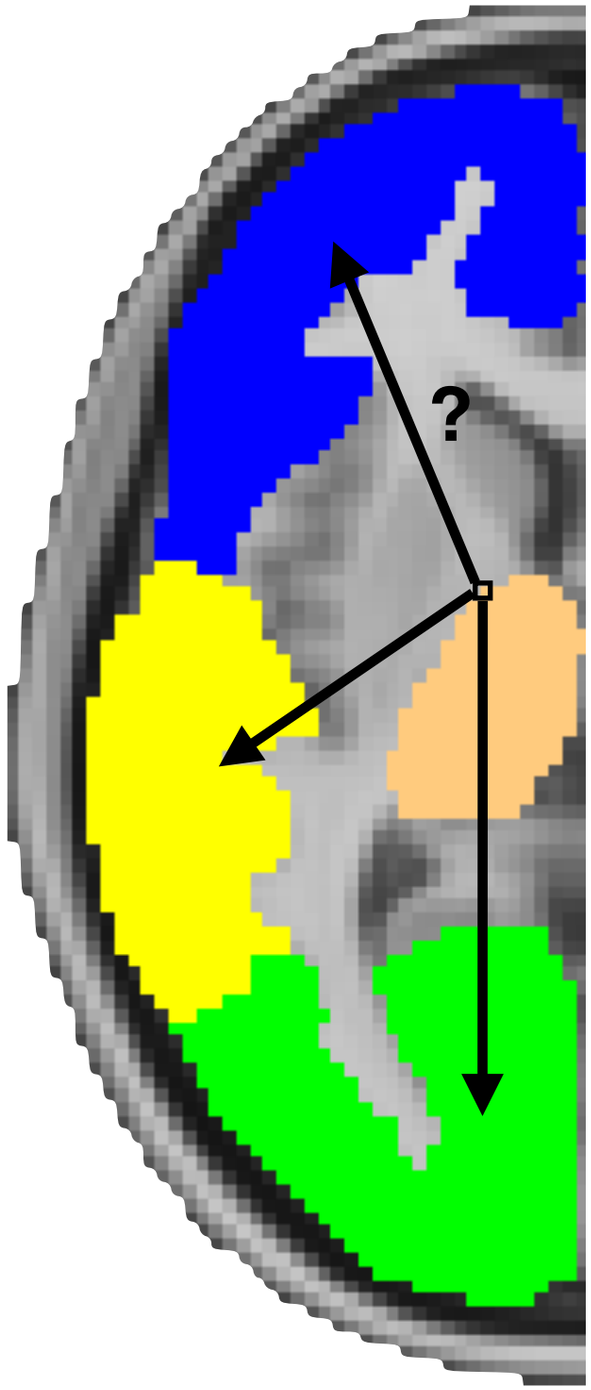
Resulting matrix:

Target ROIs

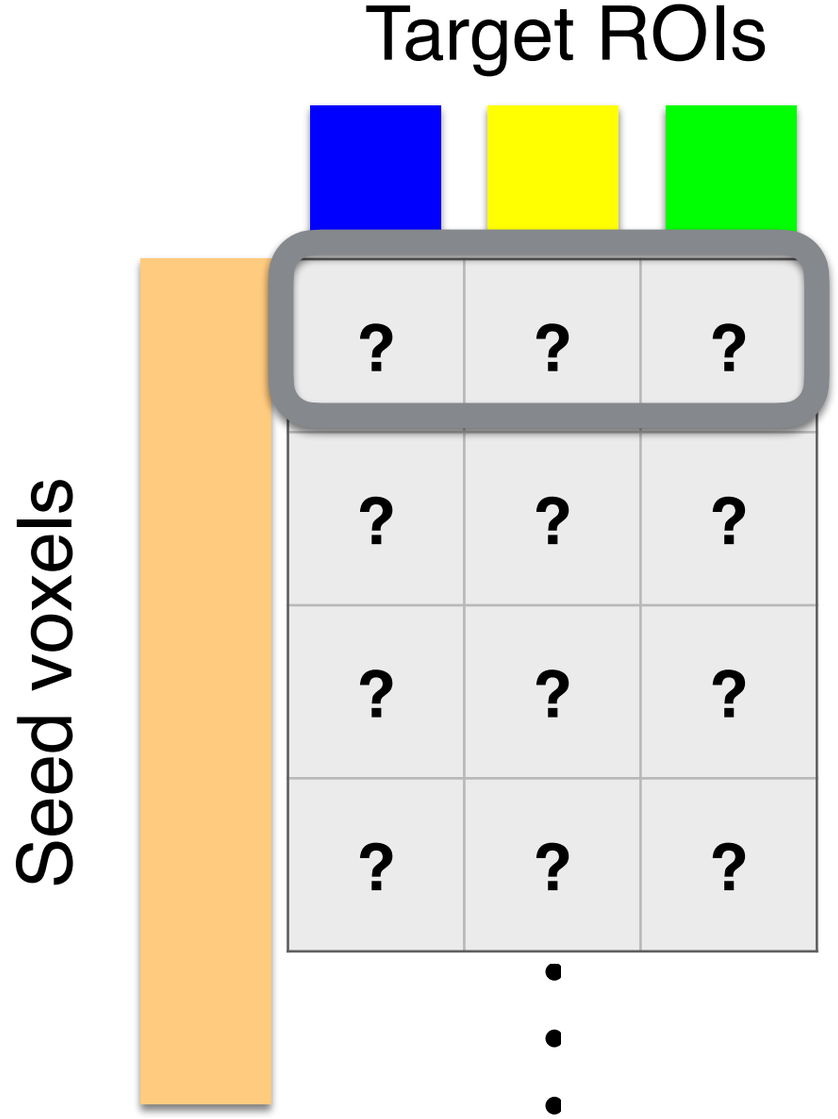
Seed voxels

?	?	?
?	?	?
?	?	?
?	?	?
•	•	•
•	•	•
•	•	•

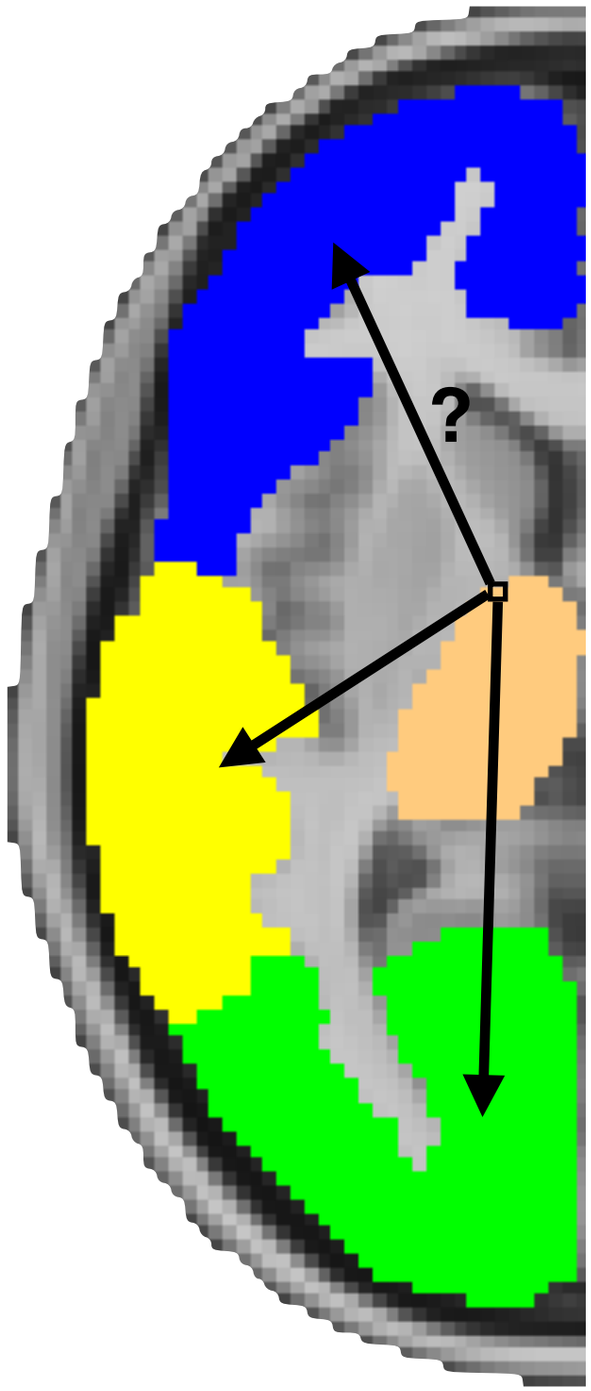
Connectivity between voxels and ROIs



Resulting matrix:

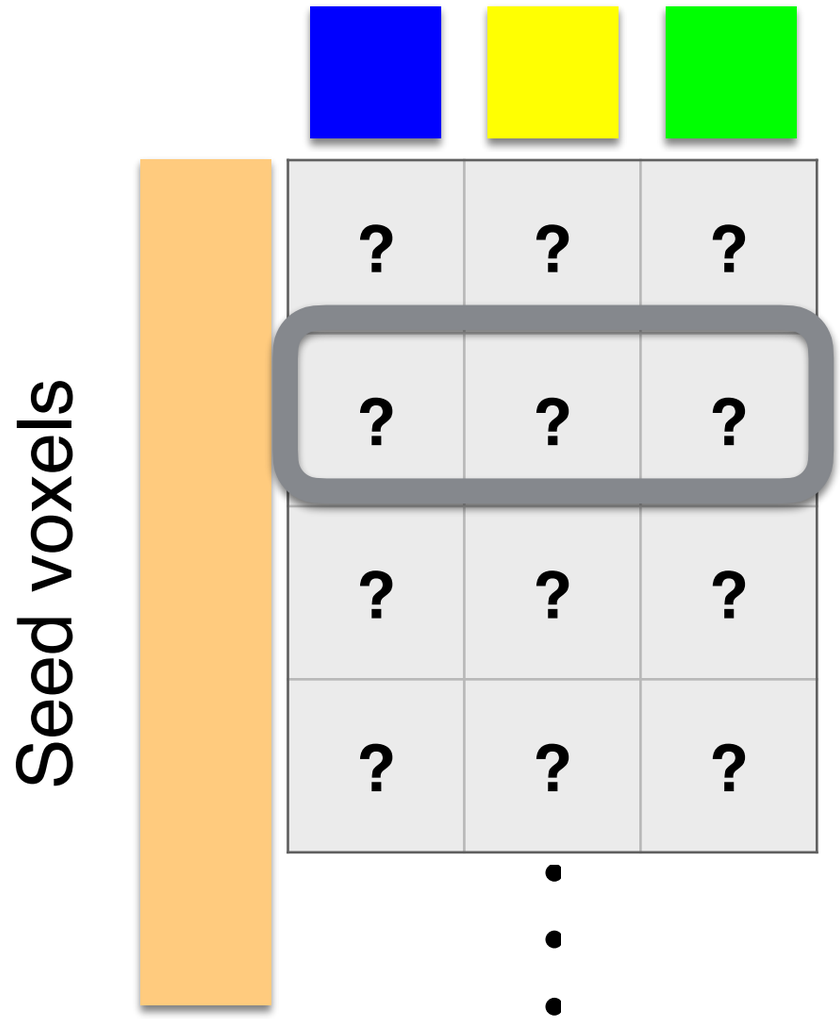


Connectivity between voxels and ROIs

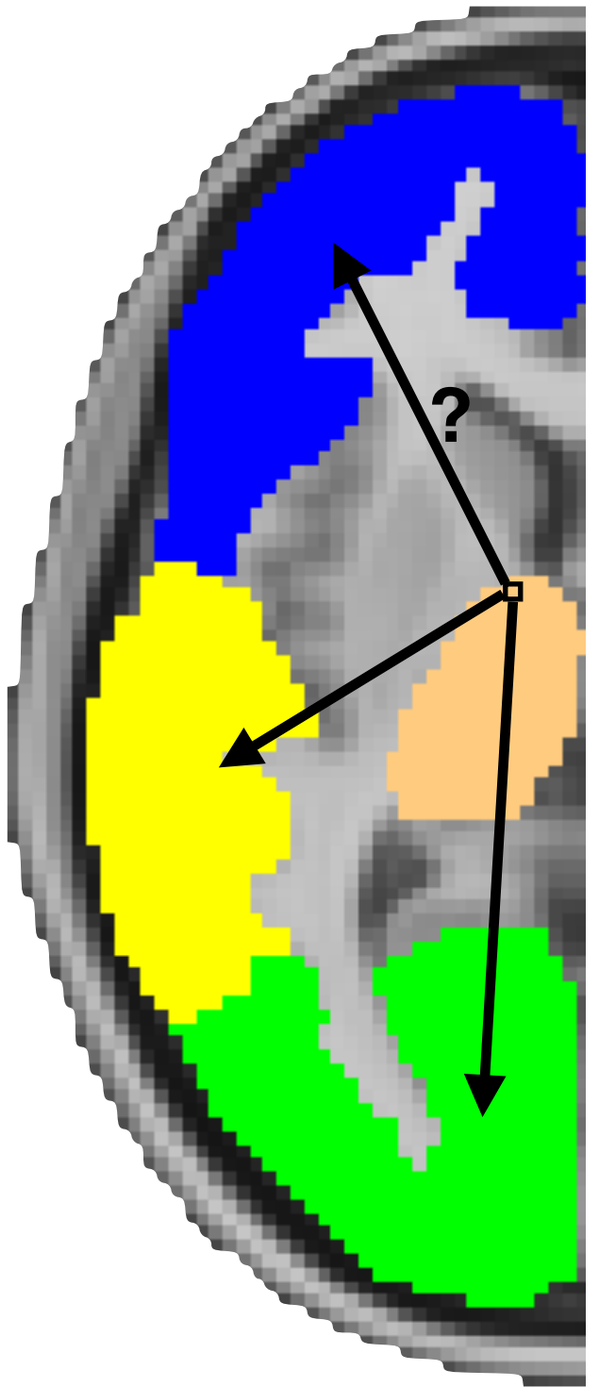


Resulting matrix:

Target ROIs

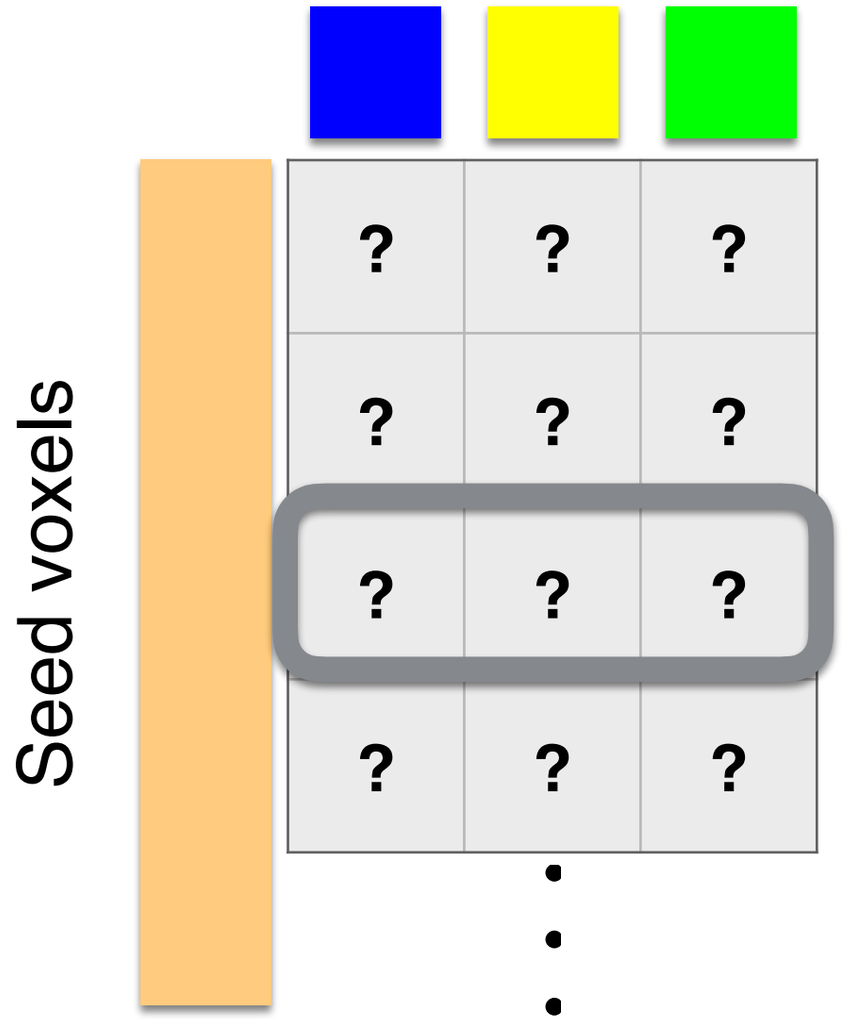


Connectivity between voxels and ROIs



Resulting matrix:

Target ROIs

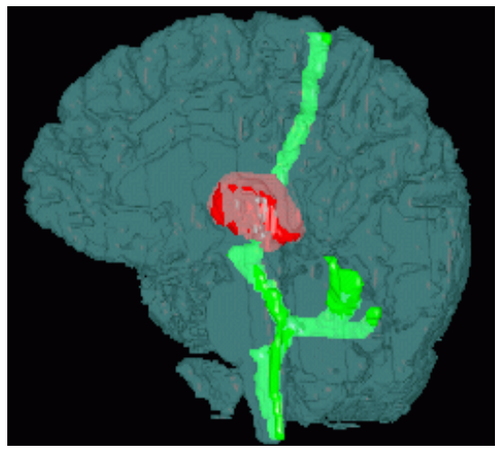


etc…

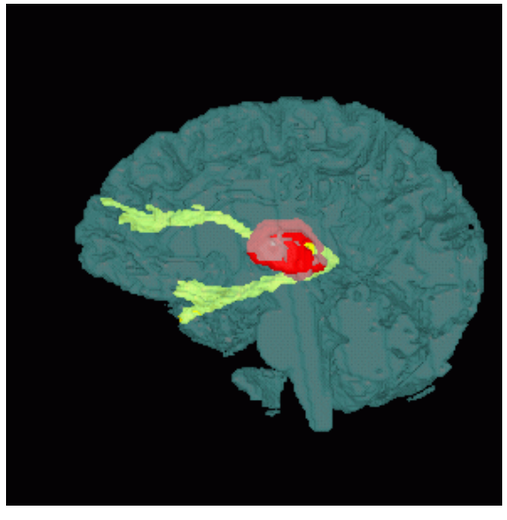
Segmenting the thalamus

no contrast on conventional MRI

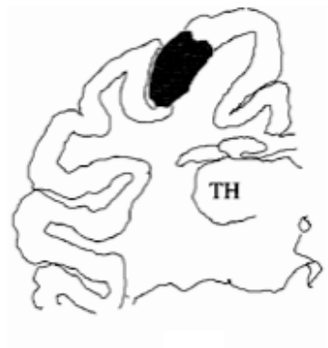
VL –> M1

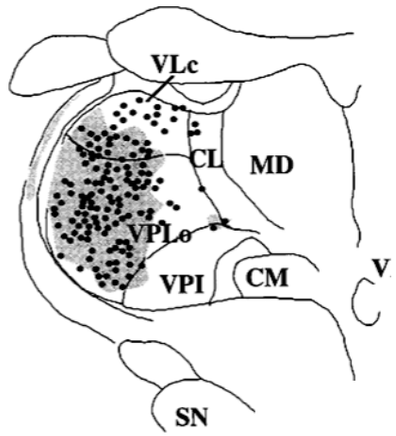


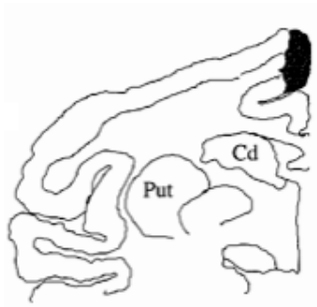
MD –> PFC

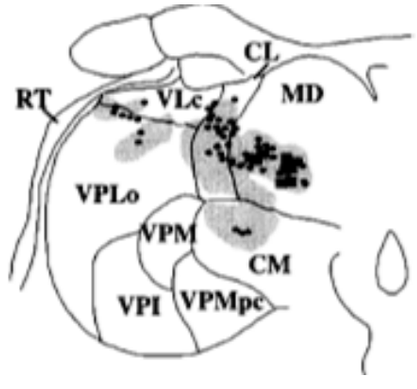


Behrens et al, 2003
(probabilistic tractography)





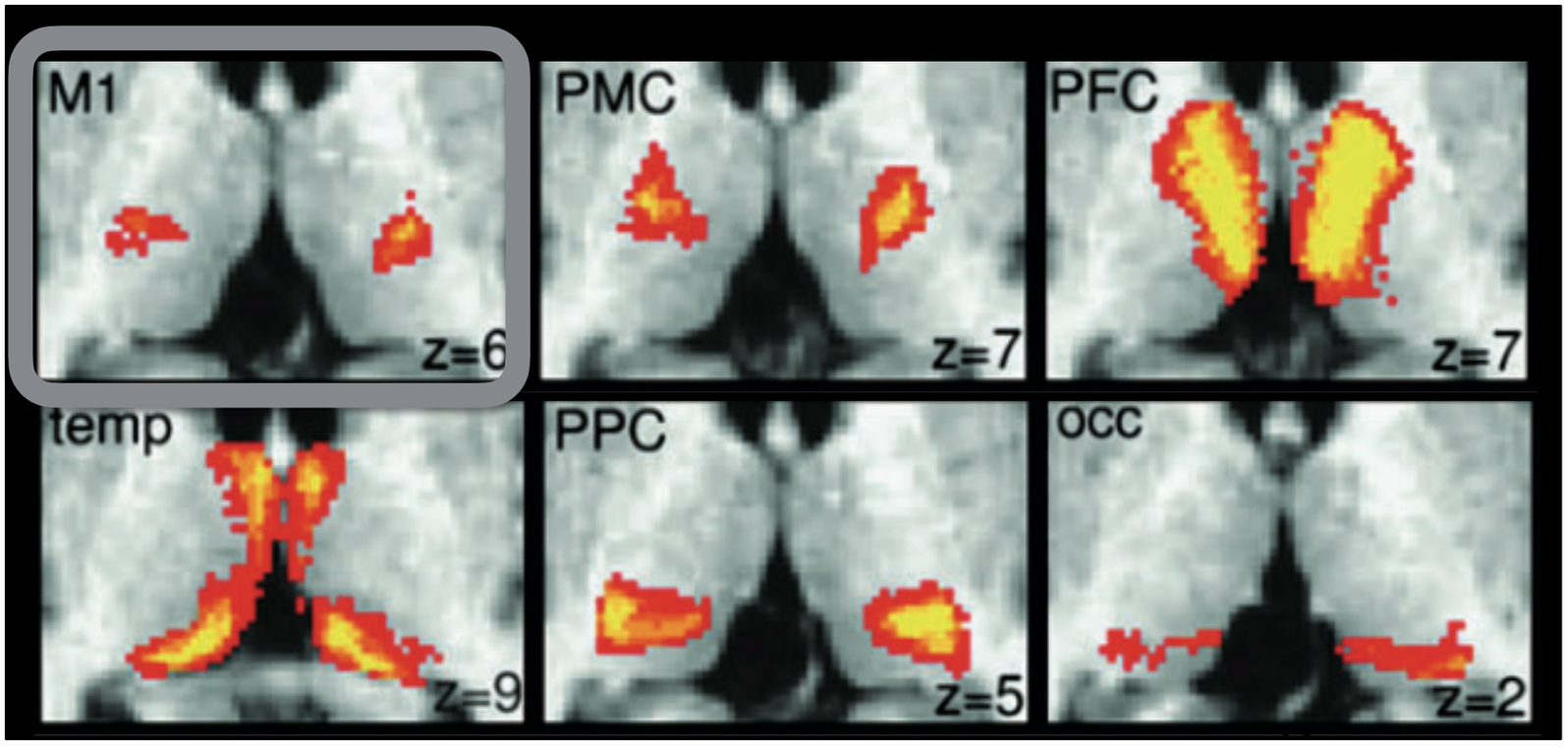




Rouiller et al, 1998
(BDA anterograde tracing)

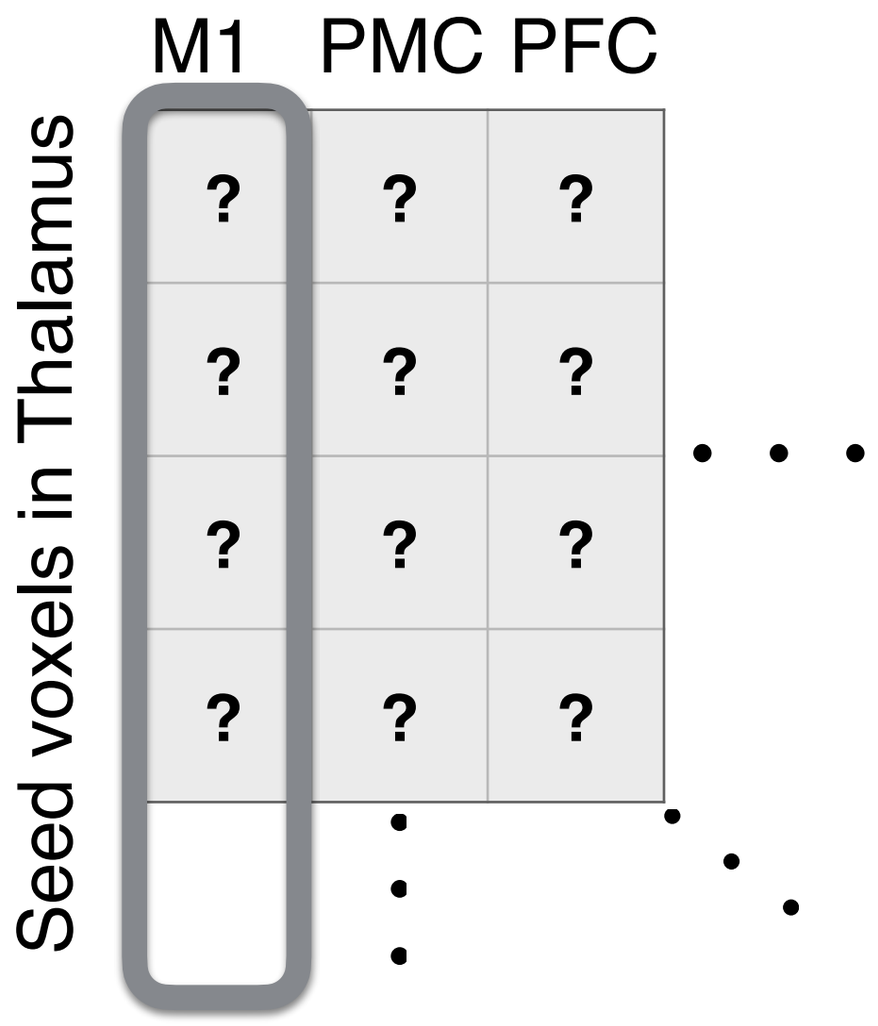
Segmenting the thalamus

Prior cortical parcelaltion



Resulting matrix:

Target ROIs

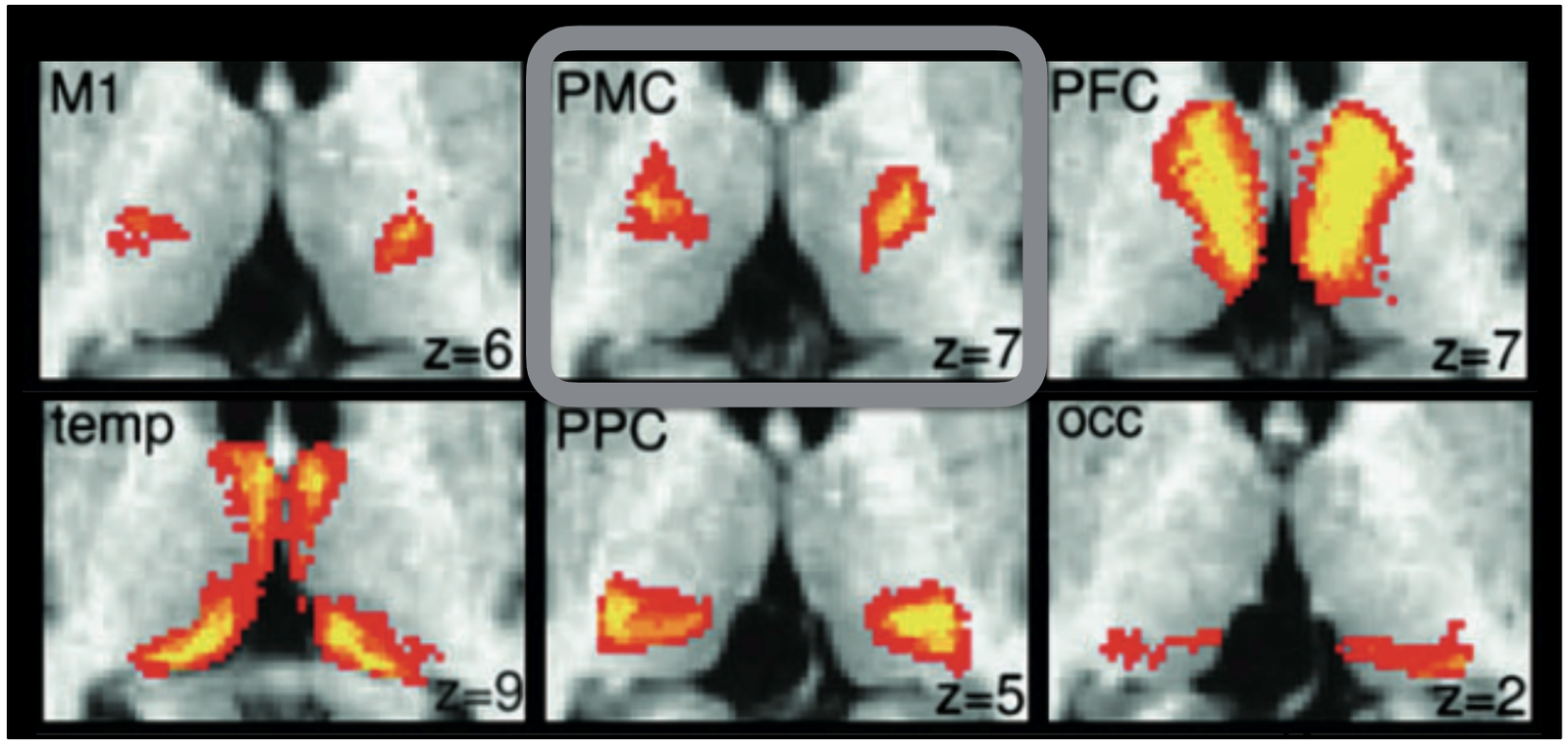


Behrens et al. Nat Neuro2003

Johansen-Berg et al. Cereb Ctx 2005

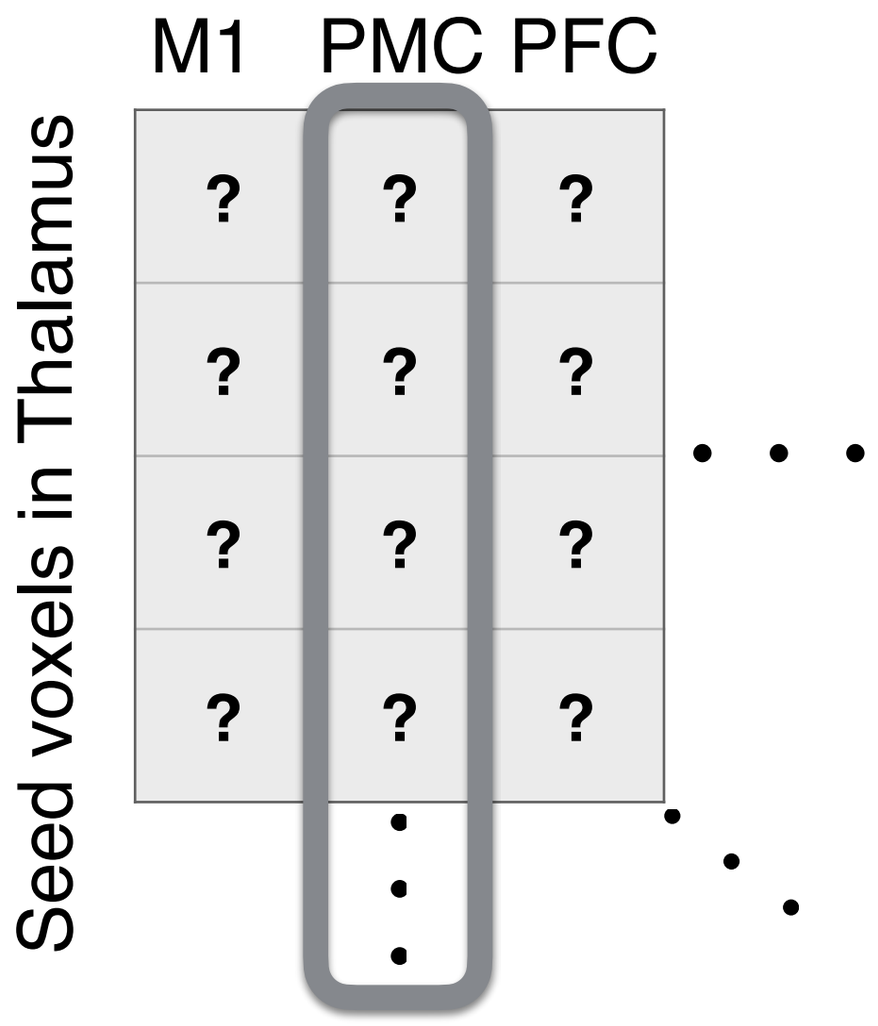
Segmenting the thalamus

Prior cortical parcelaltion



Resulting matrix:

Target ROIs

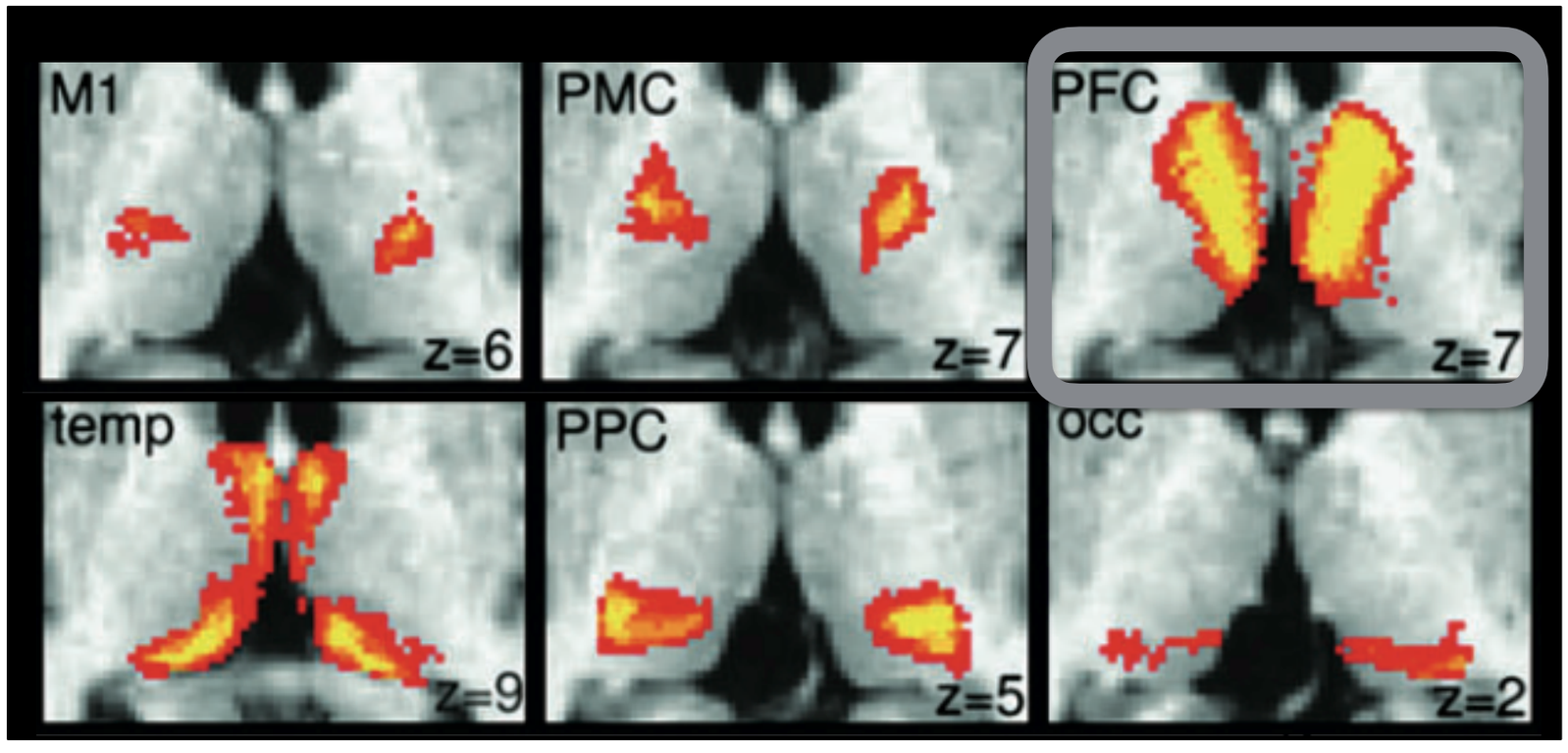


Behrens et al. Nat Neuro2003

Johansen-Berg et al. Cereb Ctx 2005

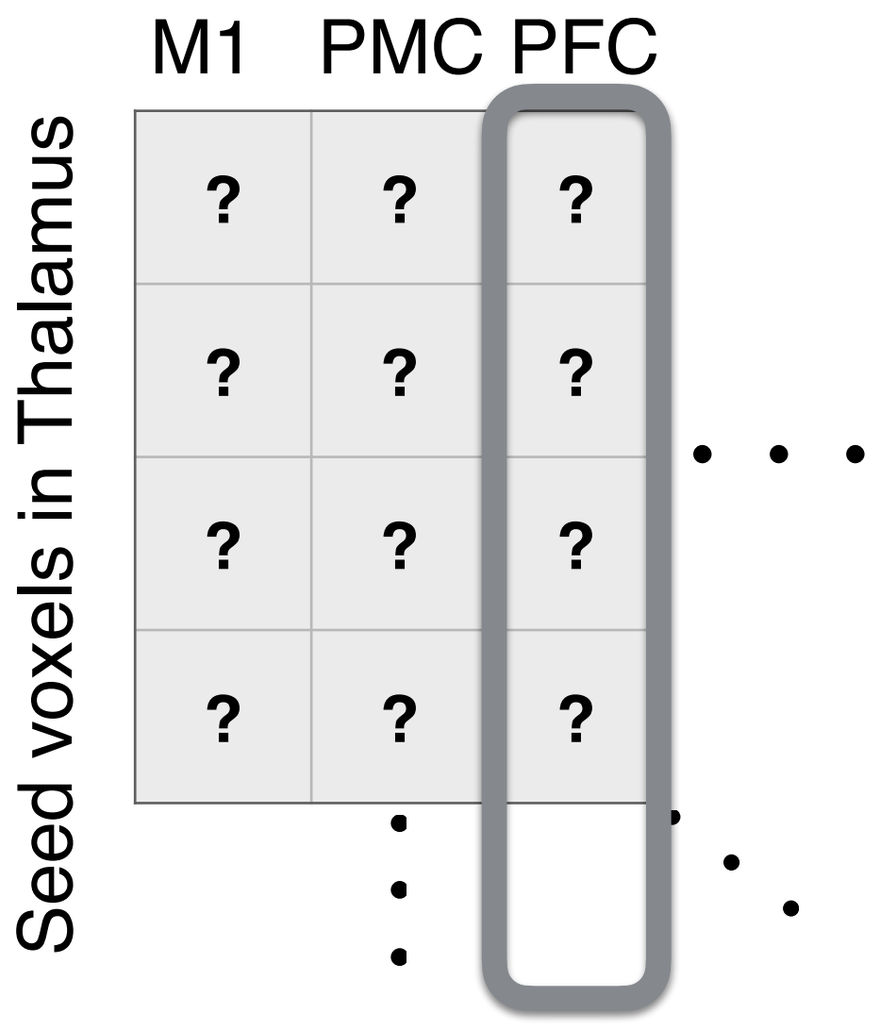
Segmenting the thalamus

Prior cortical parcelaltion



Resulting matrix:

Target ROIs



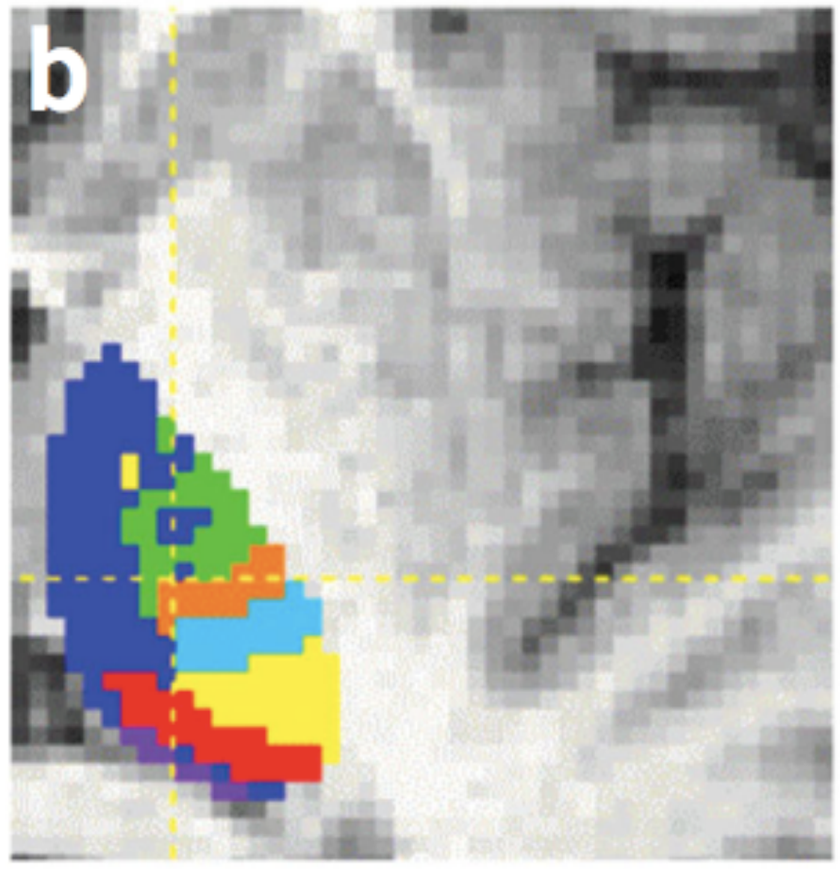
Behrens et al. Nat Neuro2003

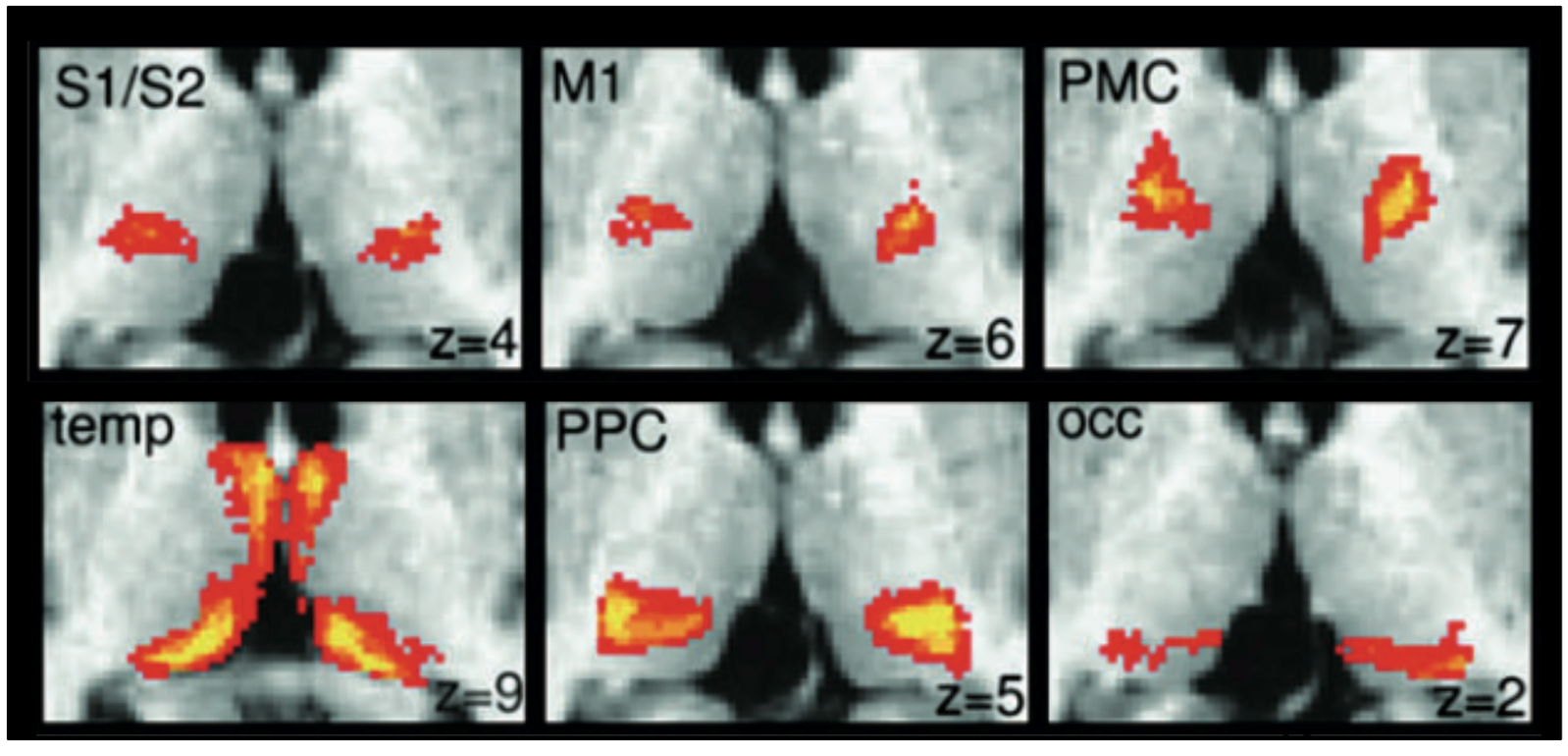
Johansen-Berg et al. Cereb Ctx 2005

Segmenting the thalamus

Prior cortical parcelaltion

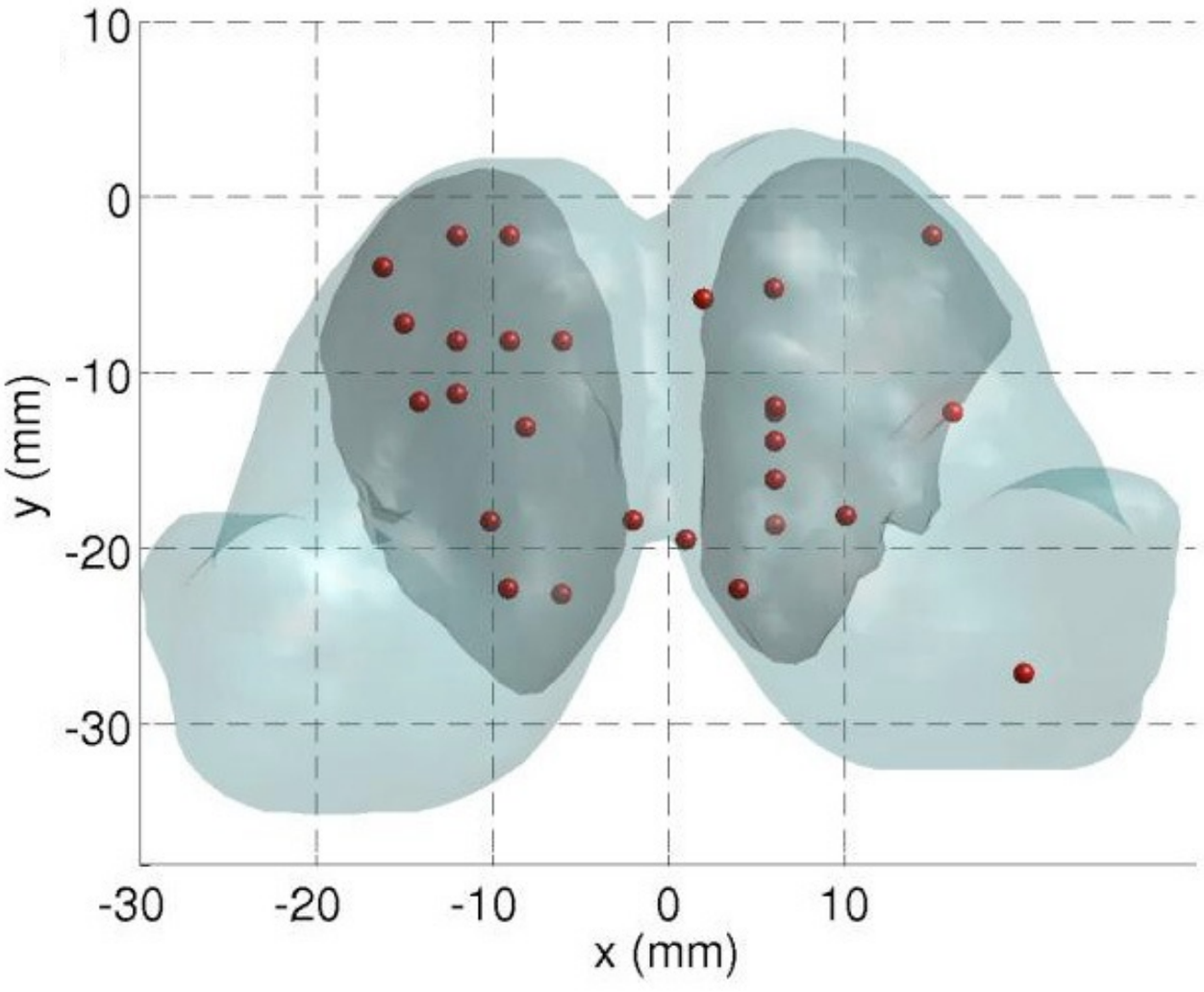
Hard thalamic parcellation



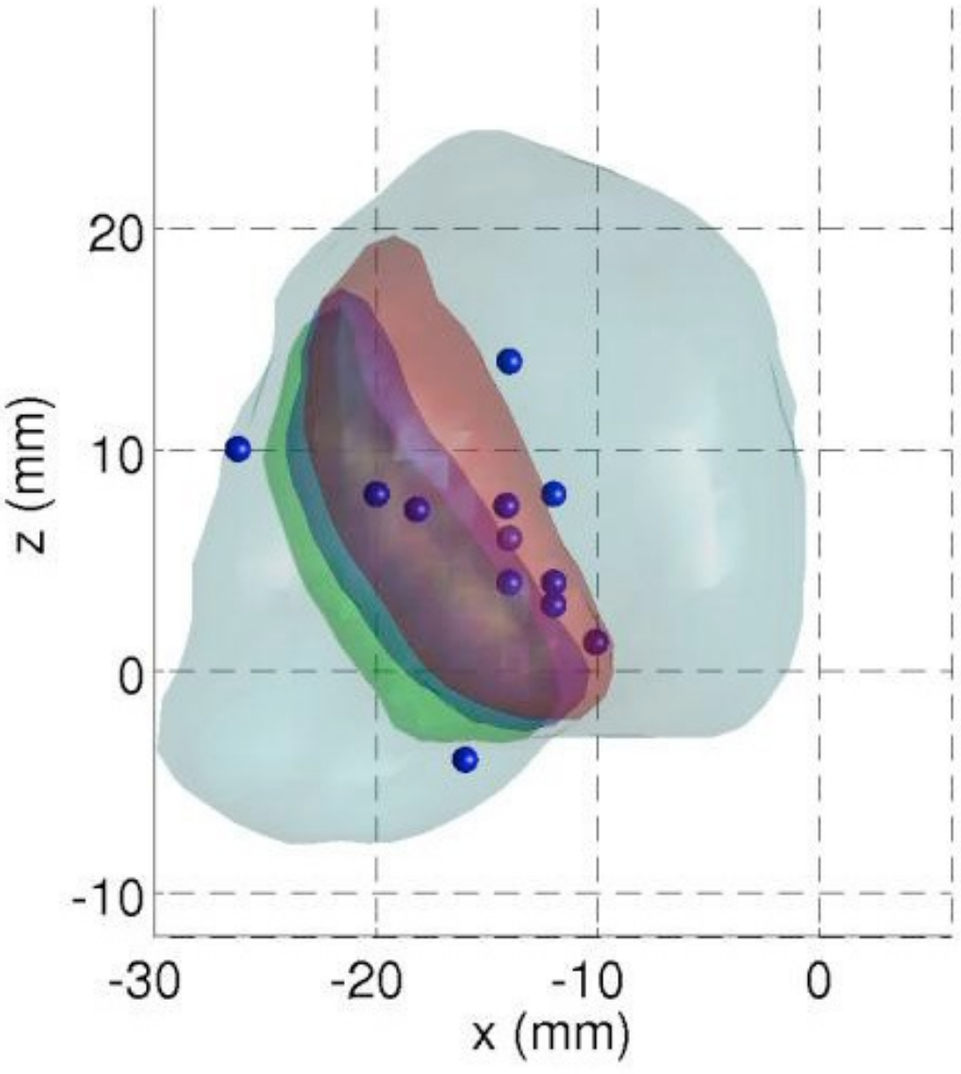


Behrens et al. Nat Neuro2003
Johansen-Berg et al. Cereb Ctx 2005

Correspondence between functional activations and connectivity-defined volumes

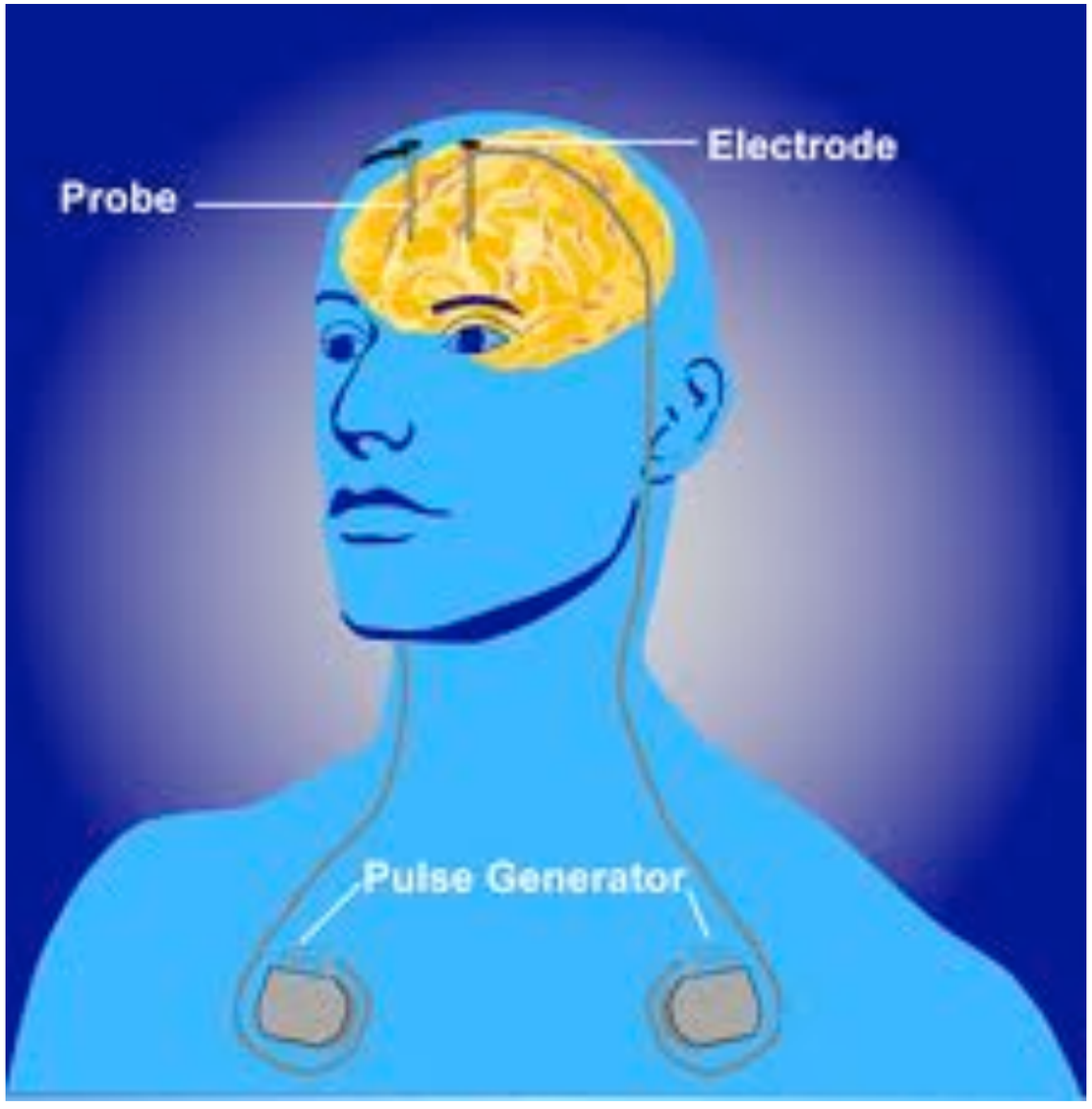


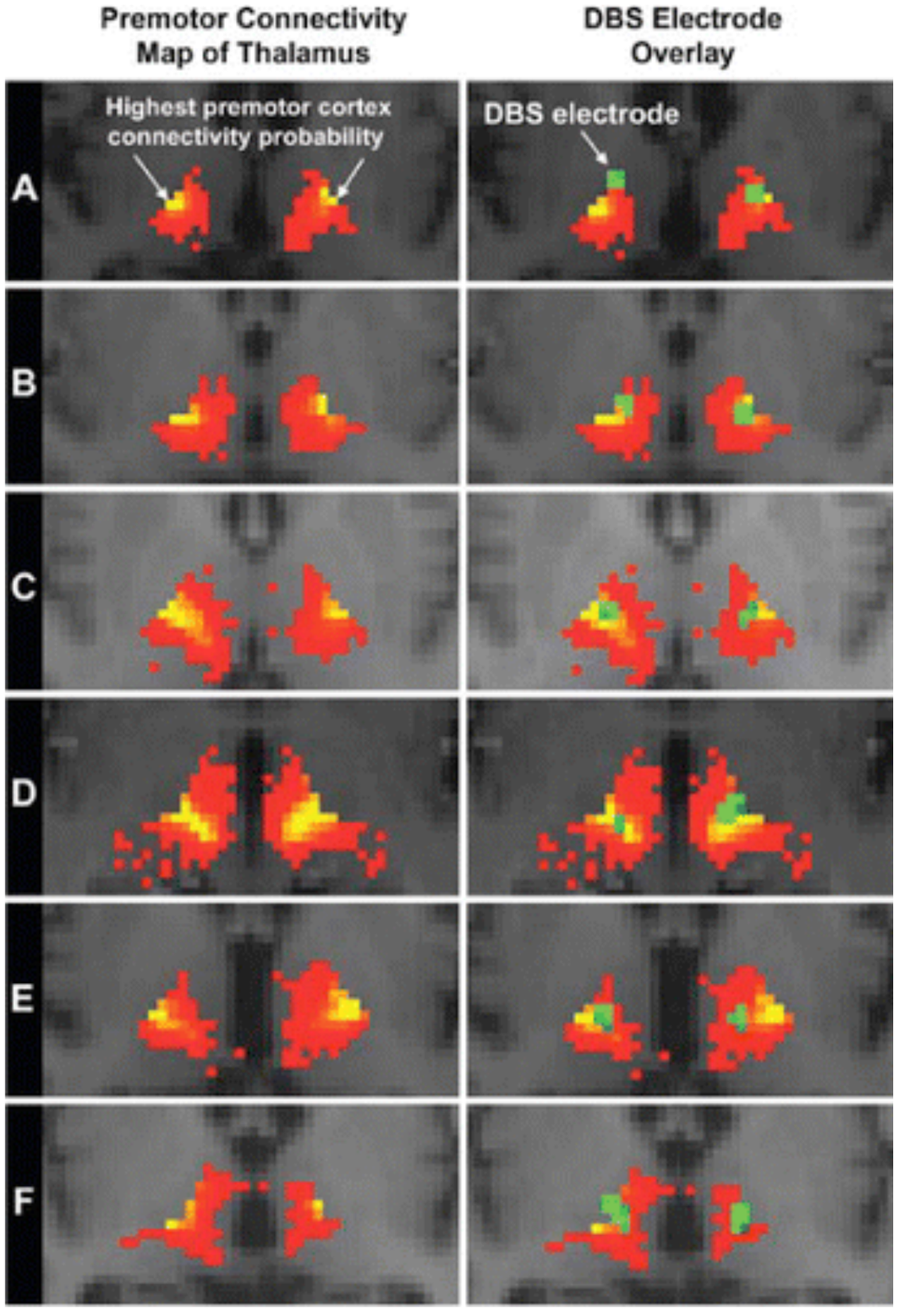
Executive Tasks



Motor Tasks

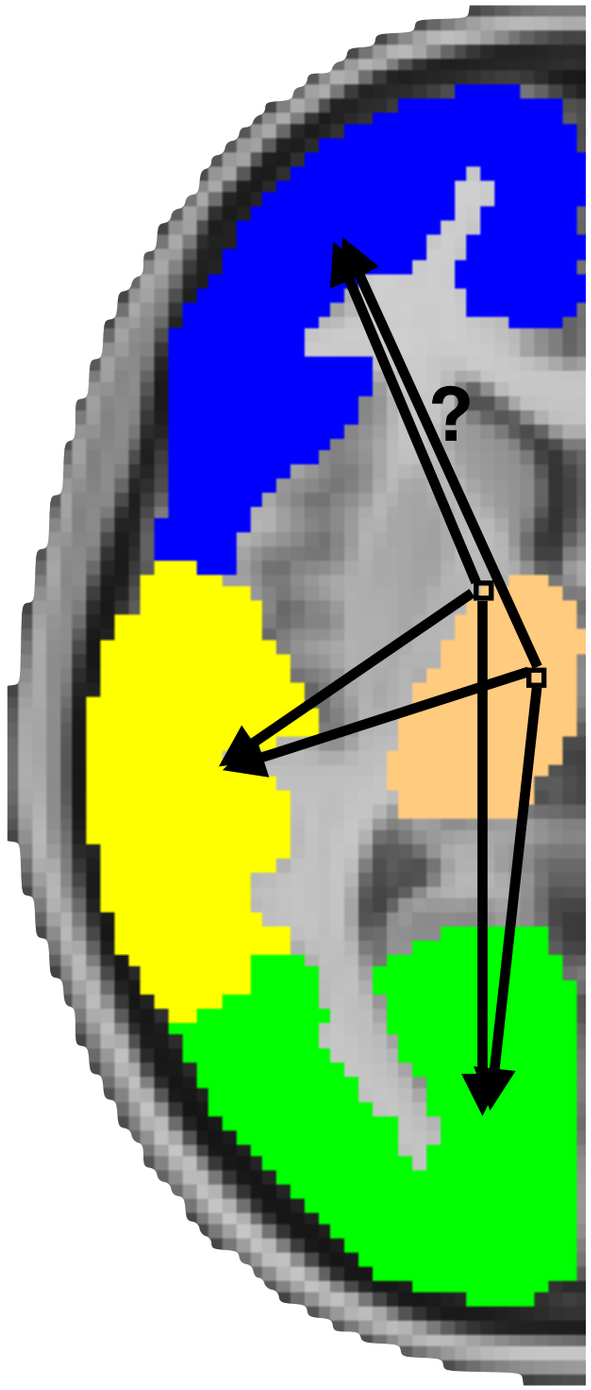
DBS for treatment of tremor in Parkinsons



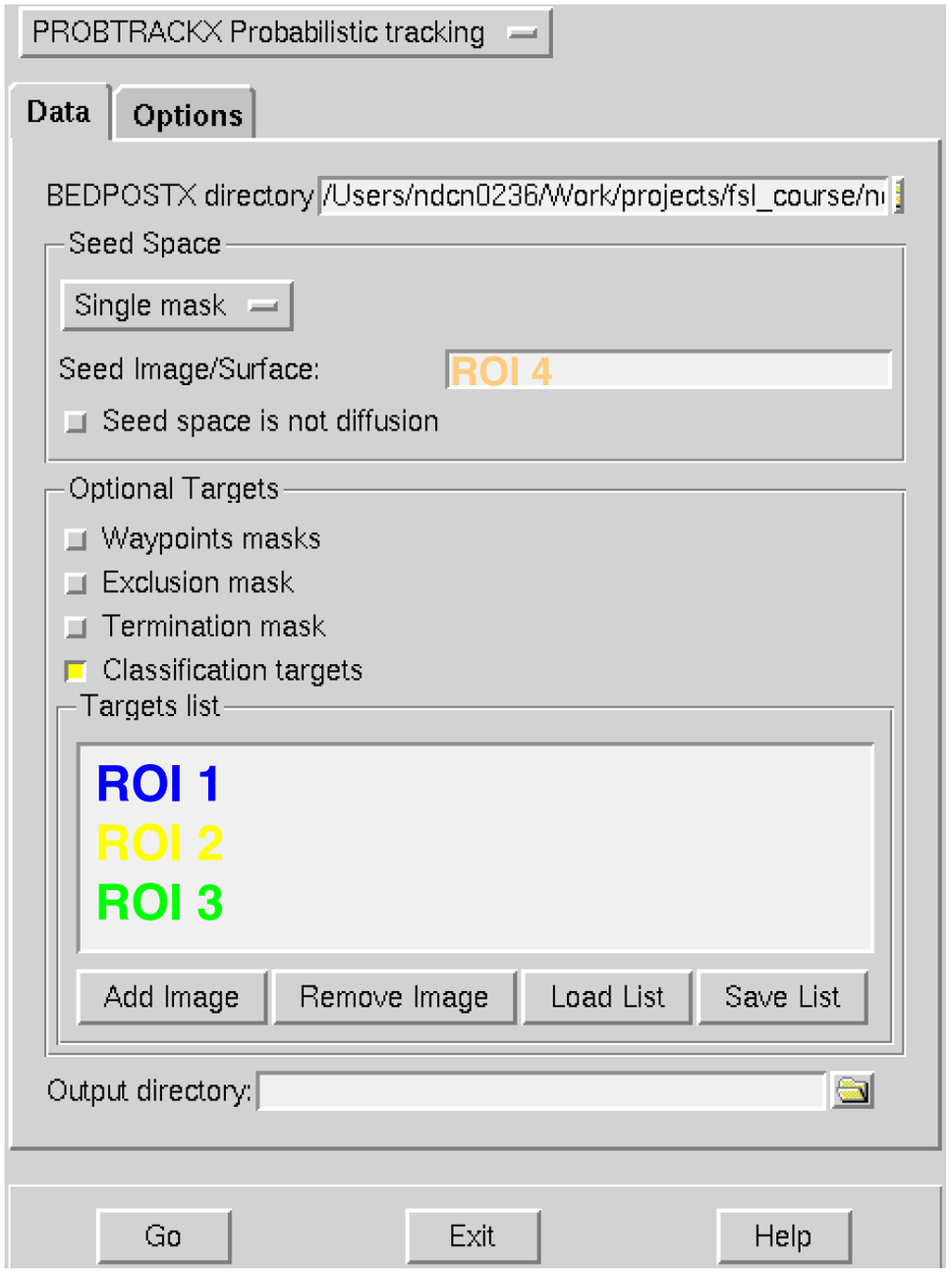


Pouratian et al. JNS 2011

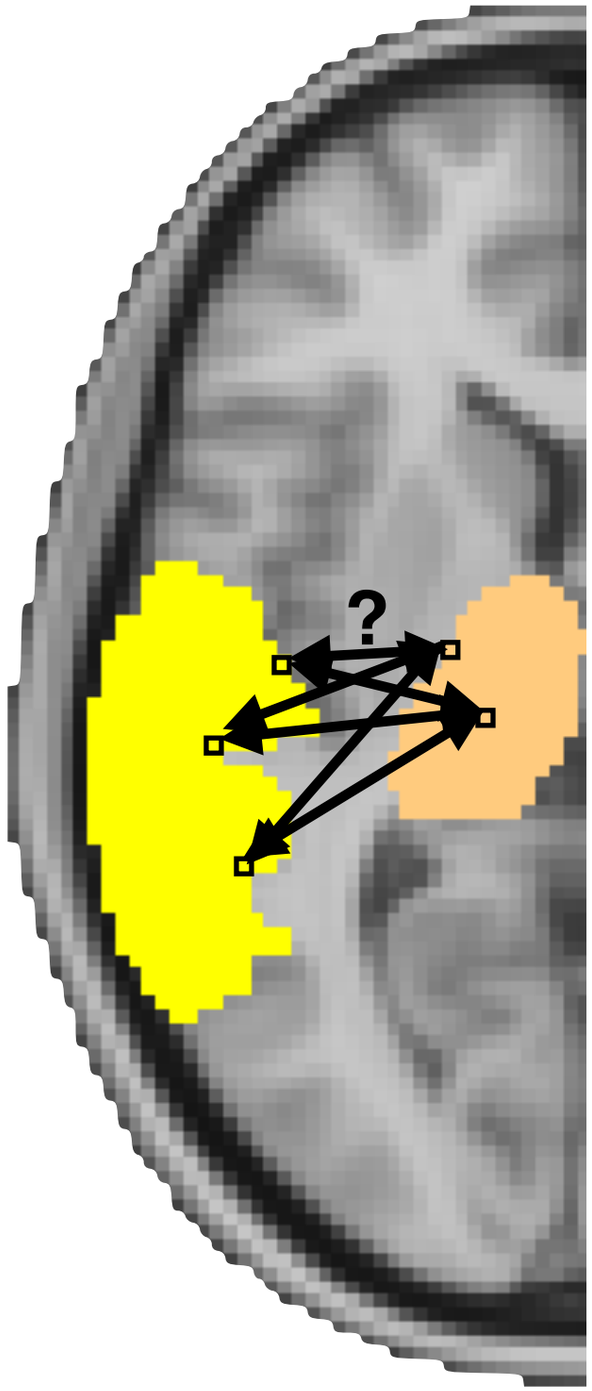
Connectivity between voxels and ROIs



Fdt GUI:



Connectivity between voxels



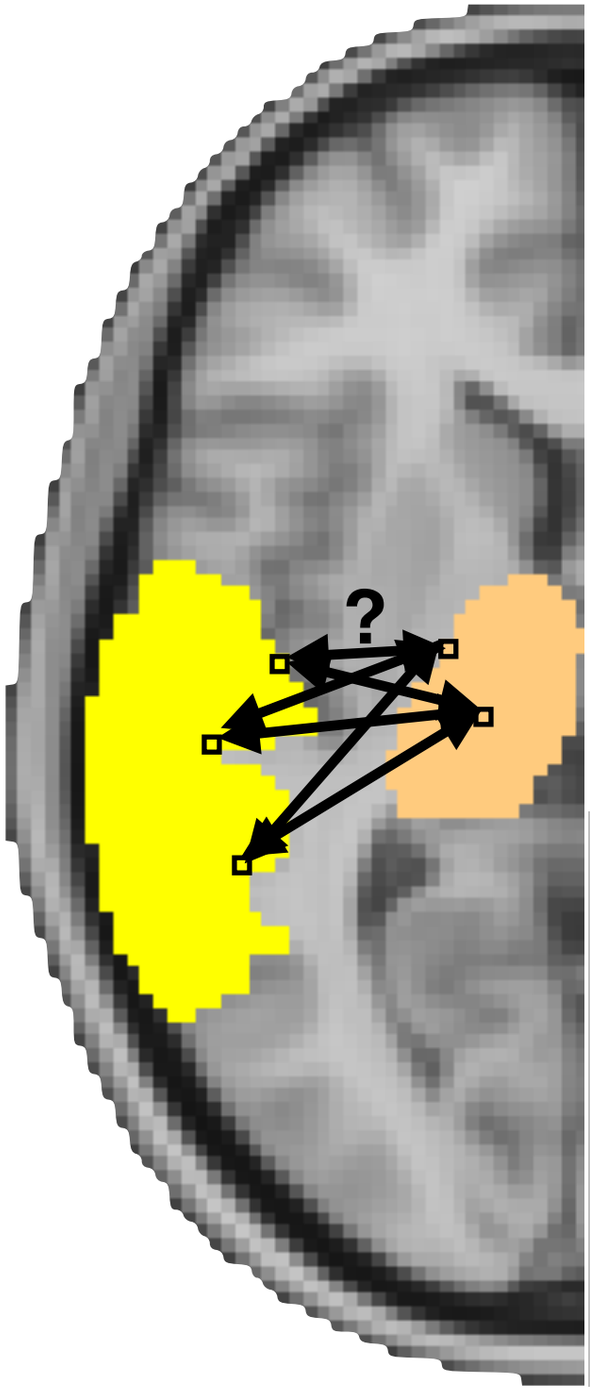
Resulting matrix:

ROI 1 voxels

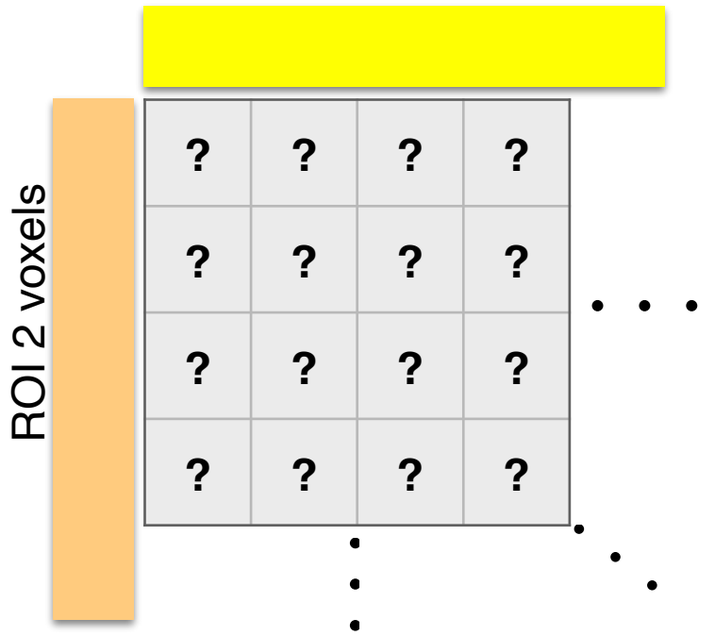
ROI 2 voxels

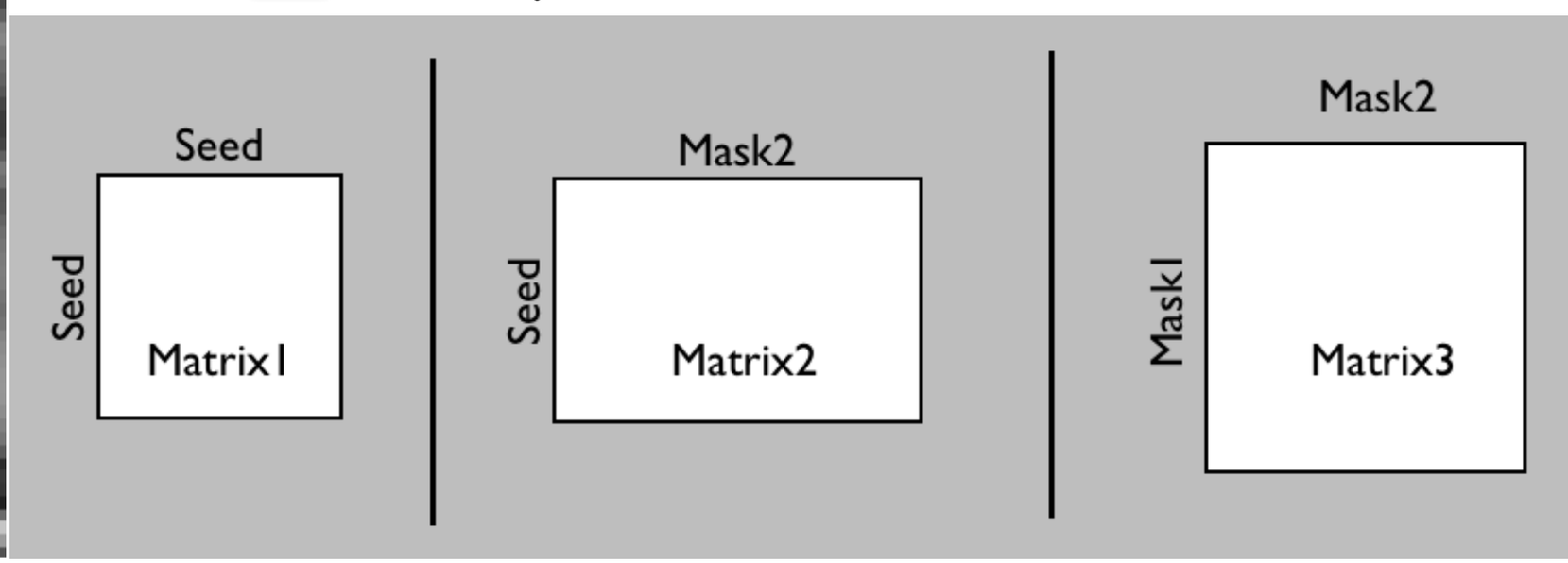
?	?	?	?
?	?	?	?
?	?	?	?
?	?	?	?

Connectivity between voxels

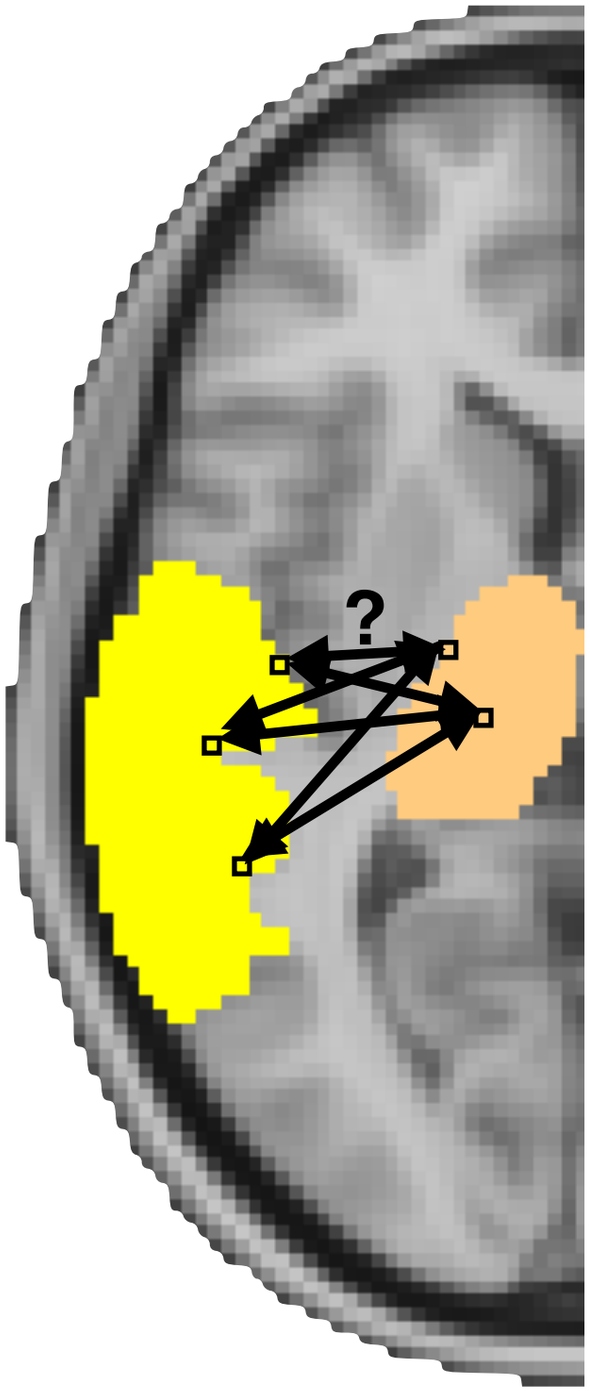


Resulting matrix:

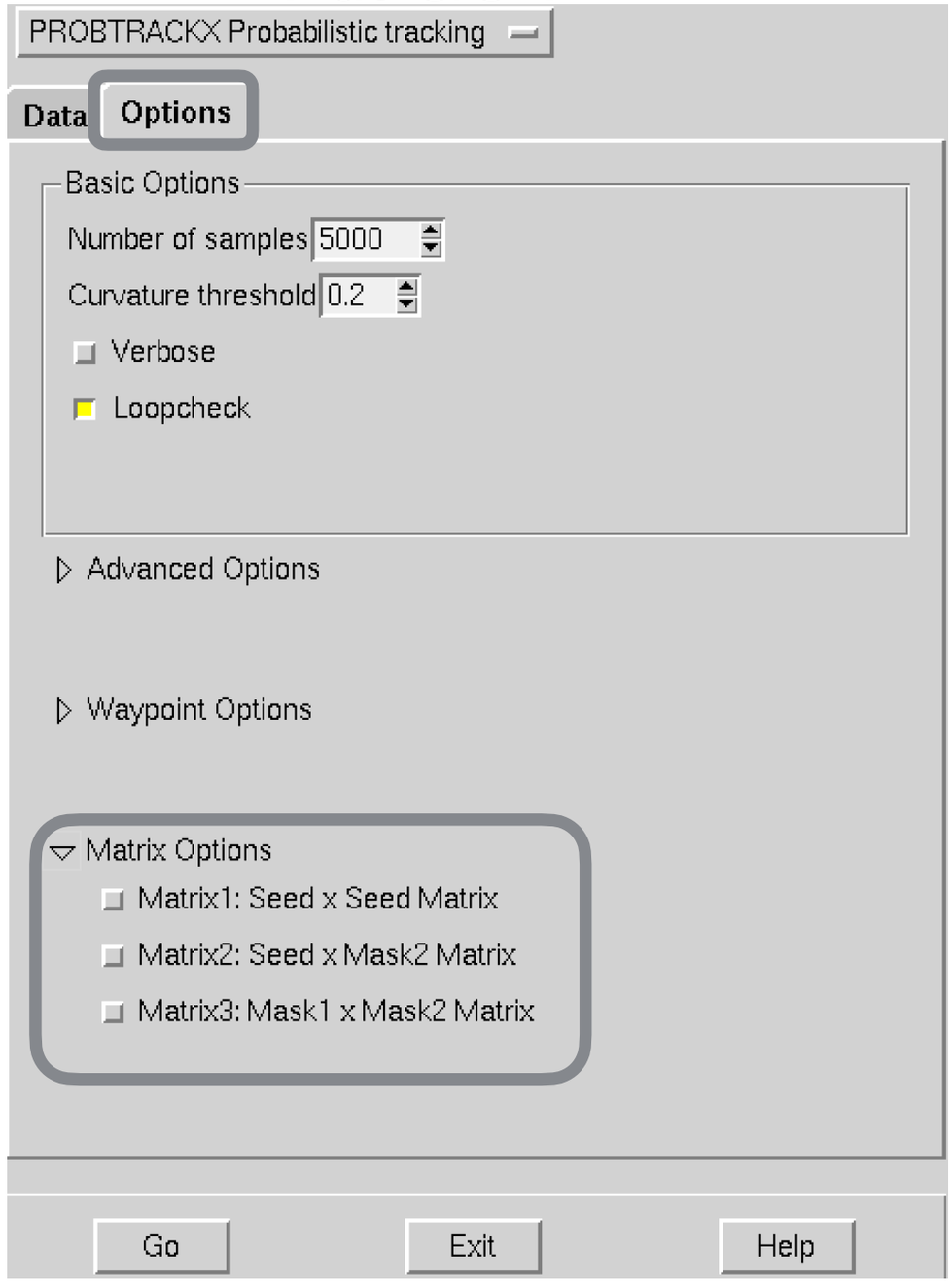




Connectivity between voxels

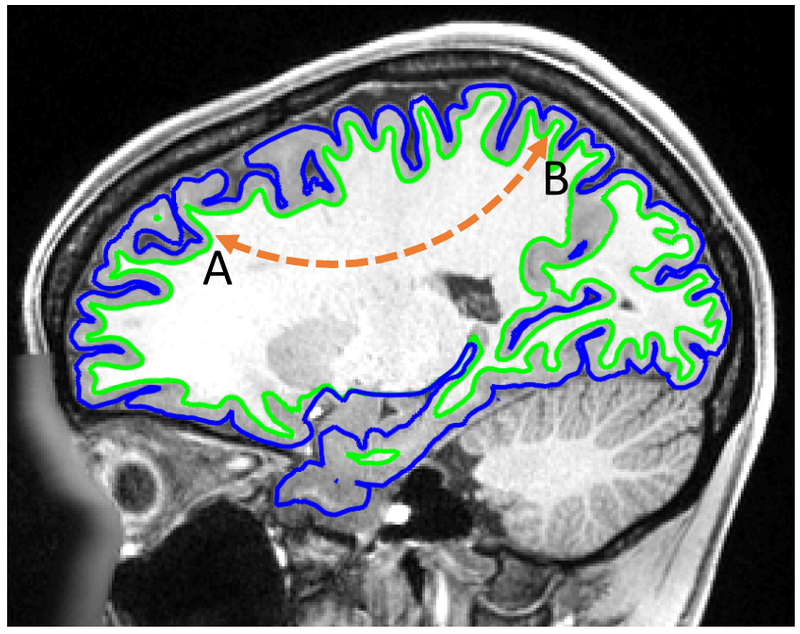


Fdt GUI:

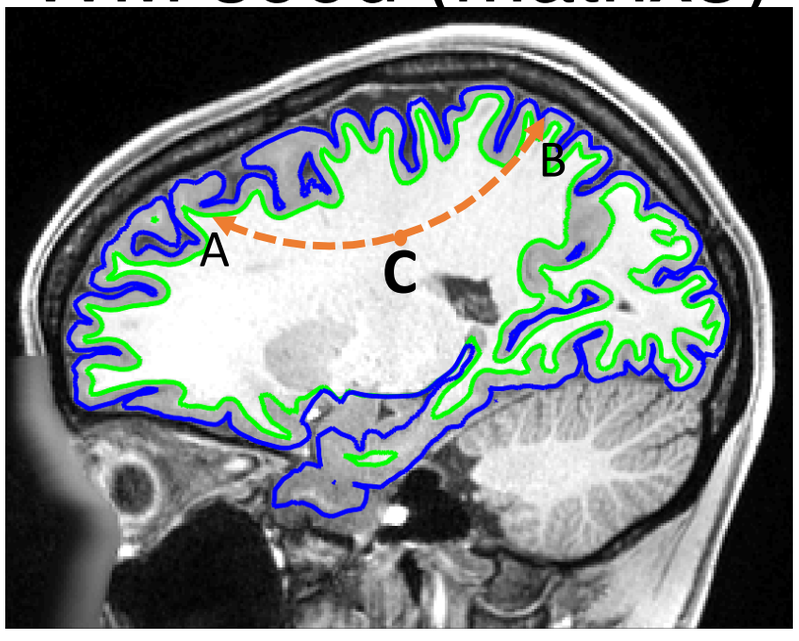


Dense connectome

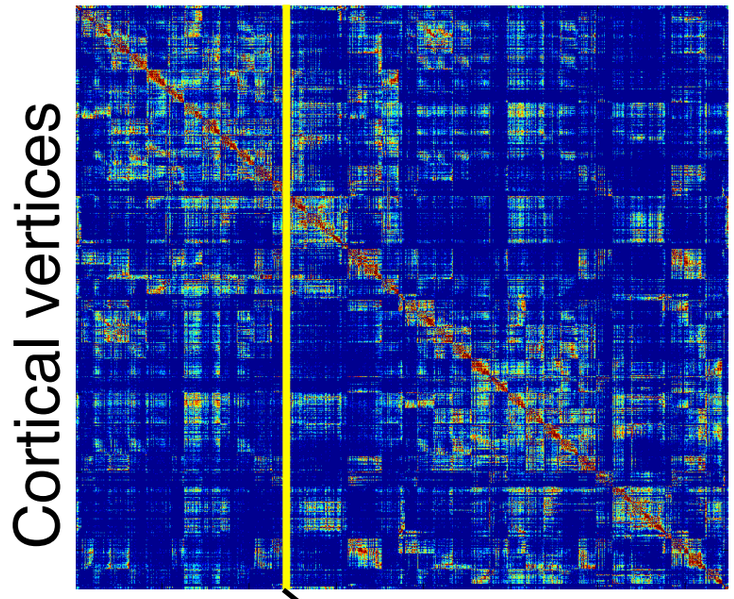
Cortical seed (matrix1)

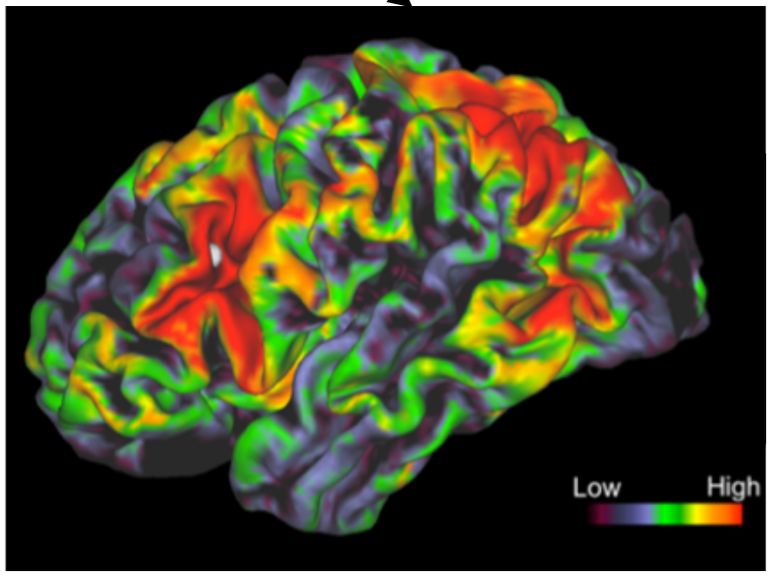


WM seed (matrix3)

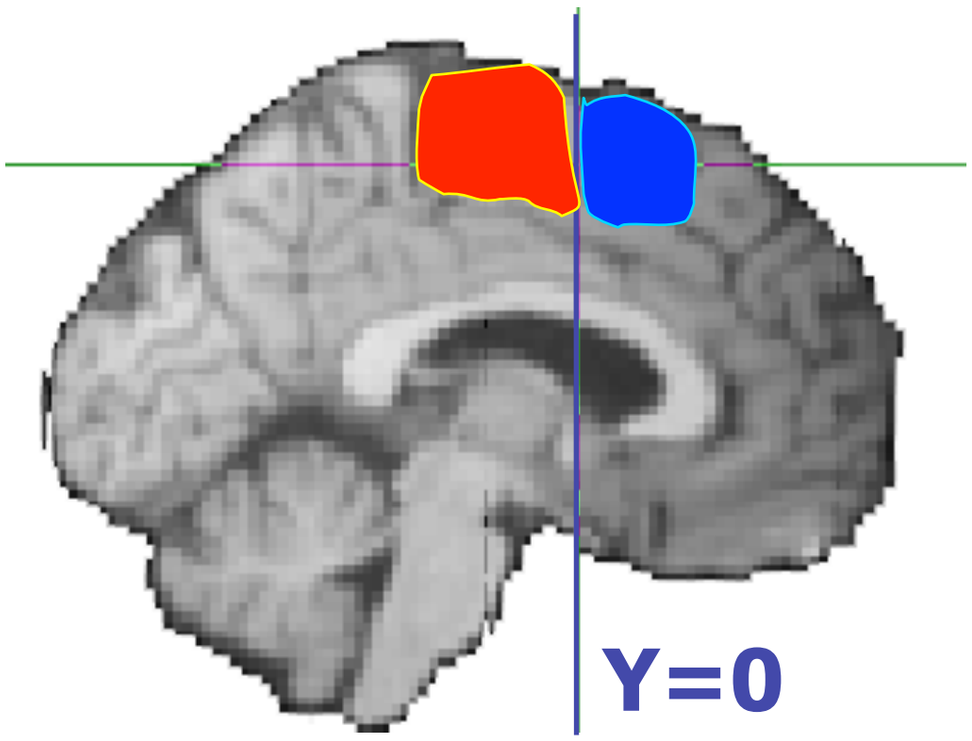


Cortical vertices





Changes in connectivity profiles
Medial Frontal Cortex

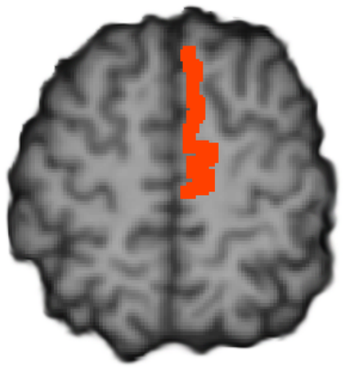


Medial area 6 contains two distinct regions with very different connectivity:

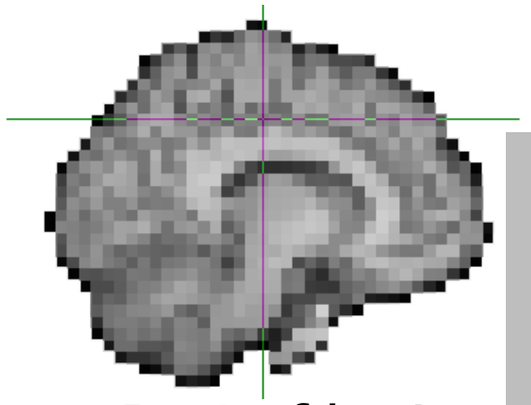
SMA and Pre-SMA

Can we define a border based on a change in connectivity profile?

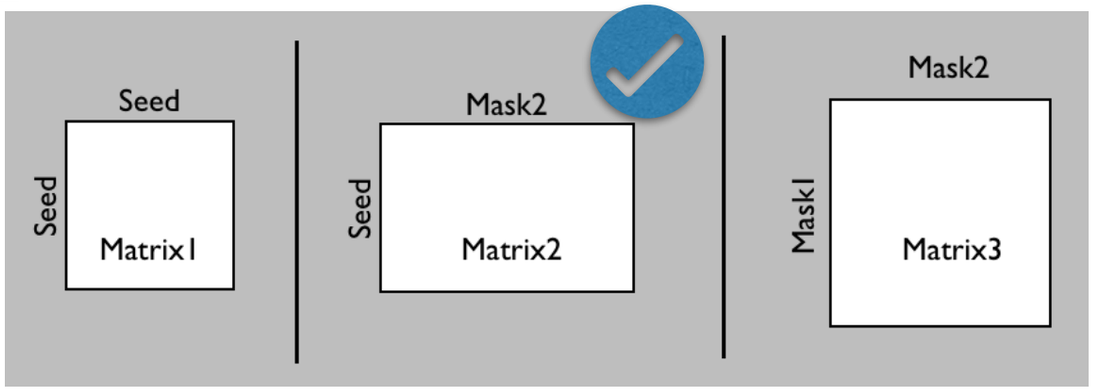
Changes in connectivity profiles Medial Frontal Cortex

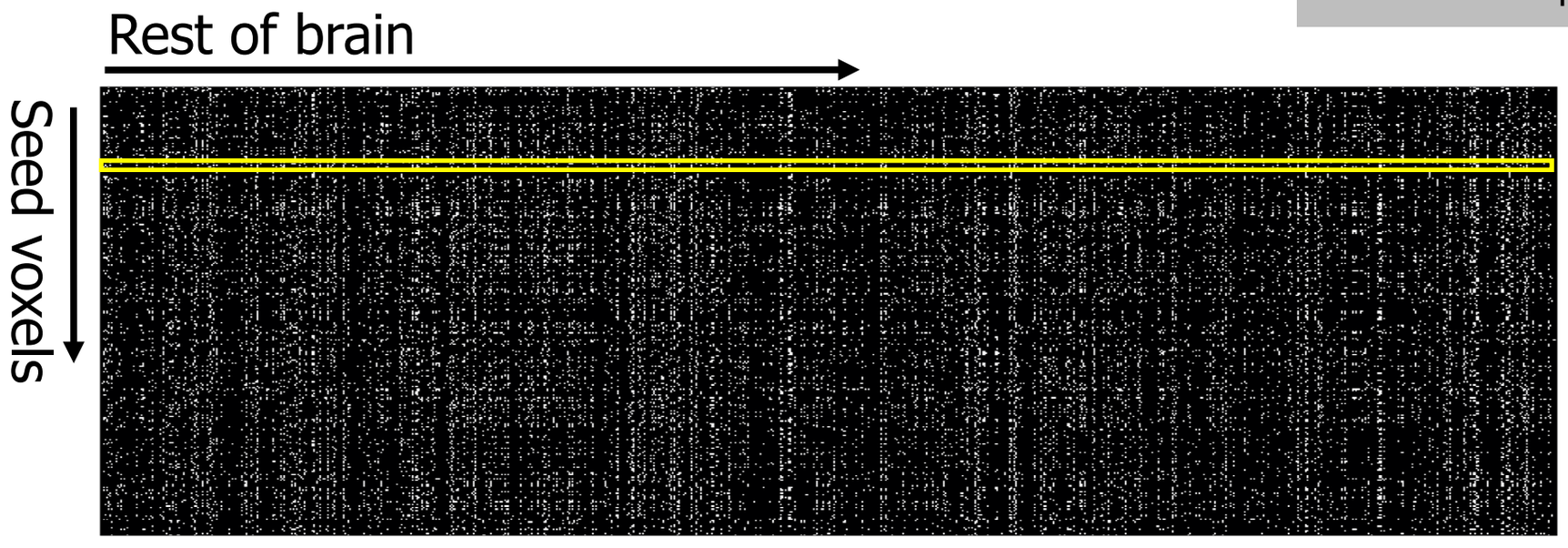


Seed voxels

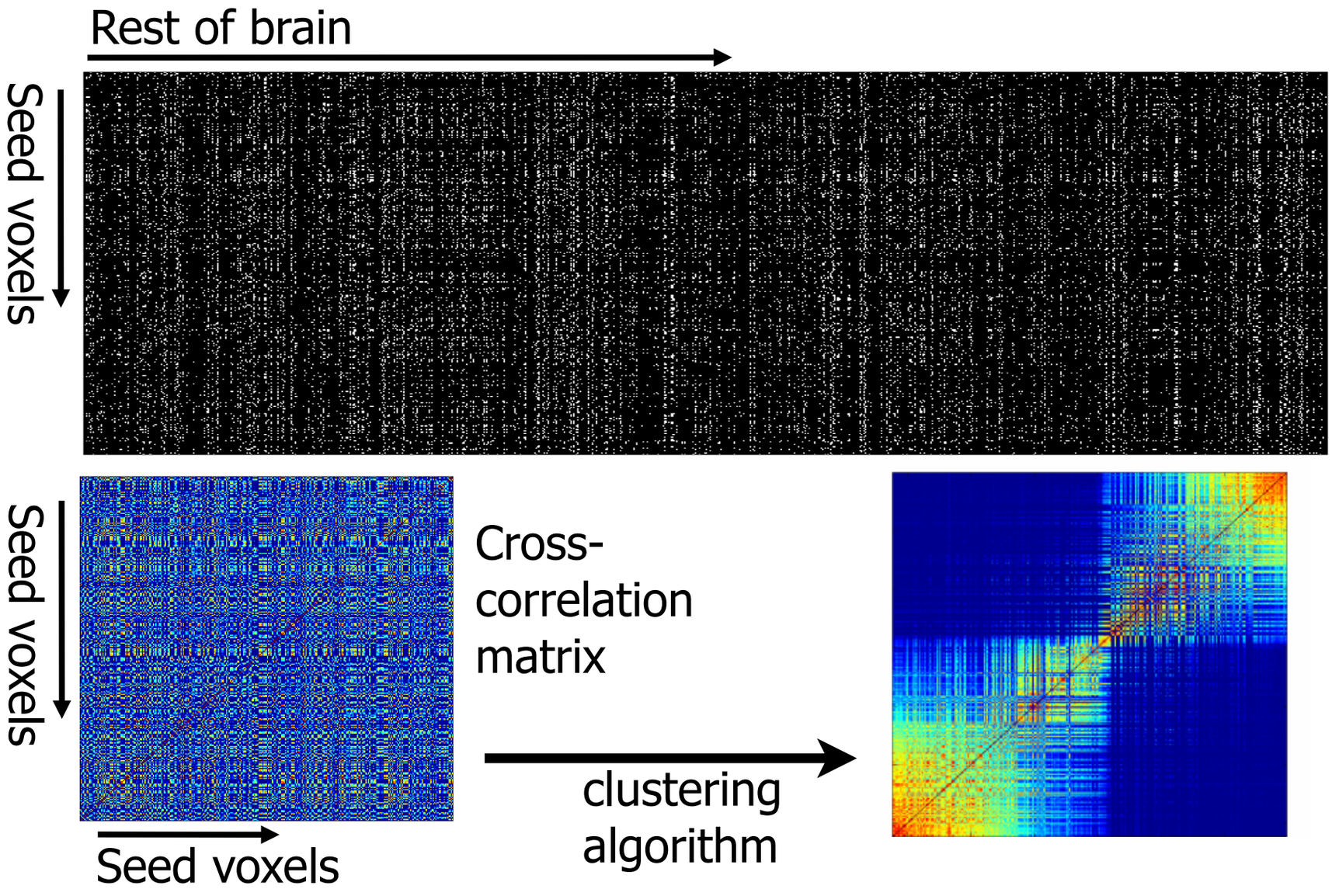


Rest of brain

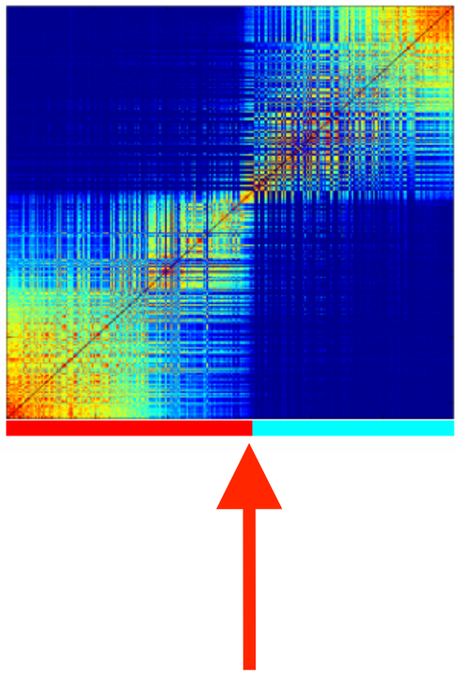




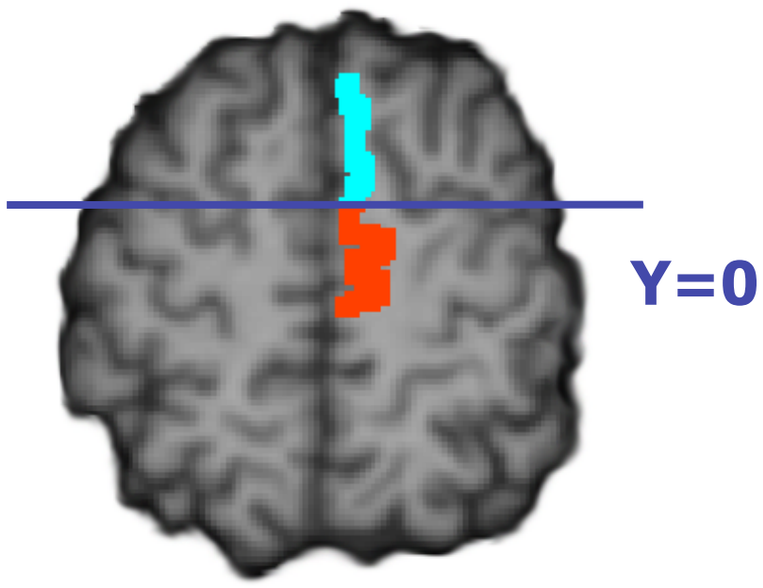
Changes in connectivity profiles Medial Frontal Cortex



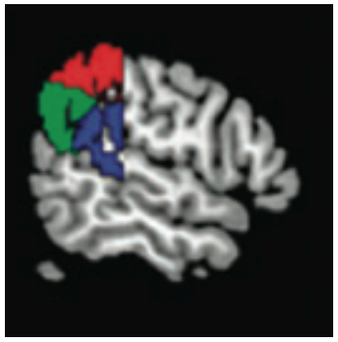
Changes in connectivity profiles Medial Frontal Cortex



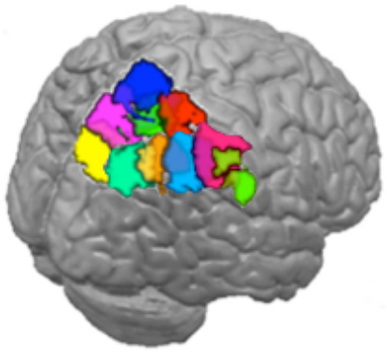
- Clusters in the re-ordered matrix represent seed voxels with similar connectivity
- Breaks between clusters represent where connectivity patterns change



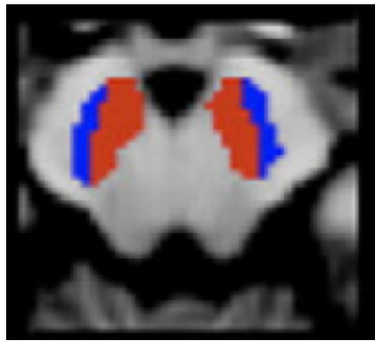
Johansen-Berg et al. 2004



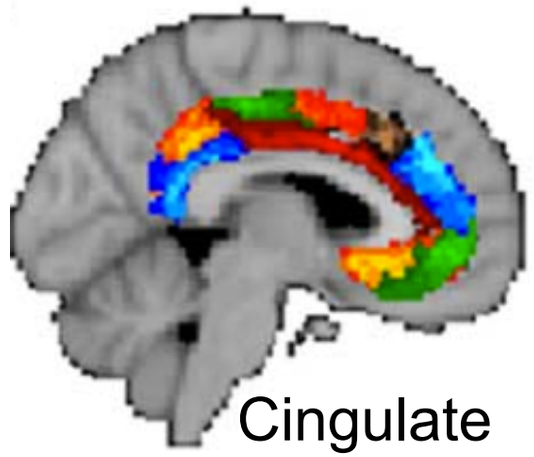
Temporo-parietal junction
Mars 2012



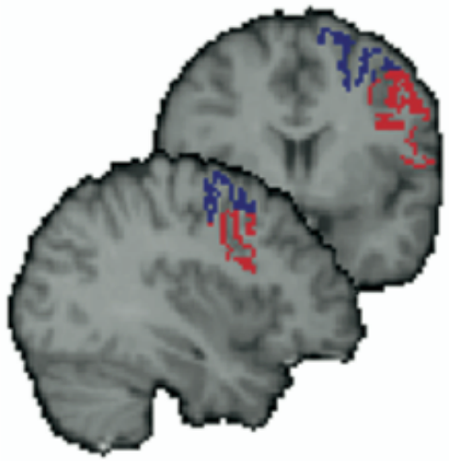
Lateral Parietal
Mars 2011



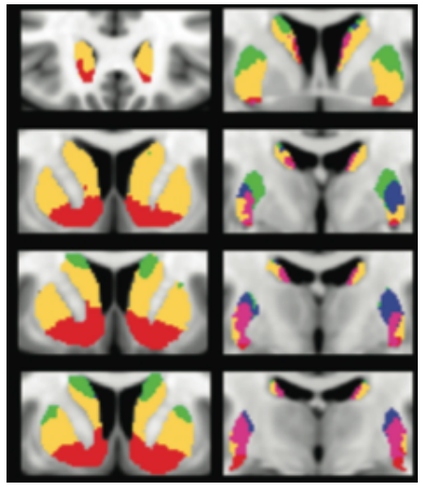
Substantia Nigra
Menke 2010



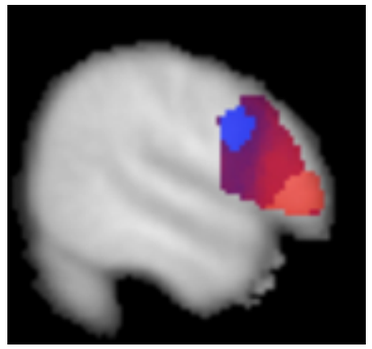
Cingulate
Beckmann 2009



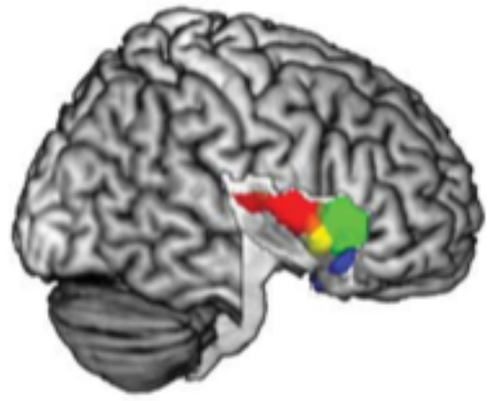
Lateral pre-motor
Tomassini 2007



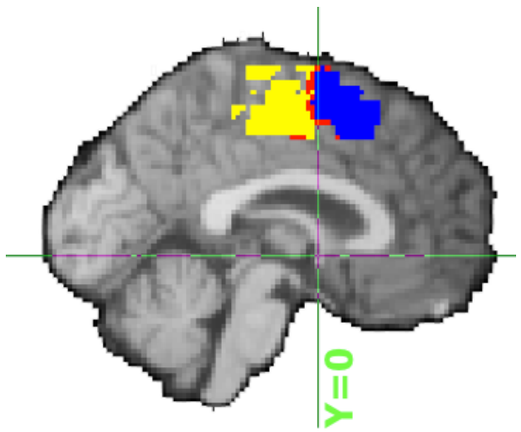
Striatum
Tziortzi 2013



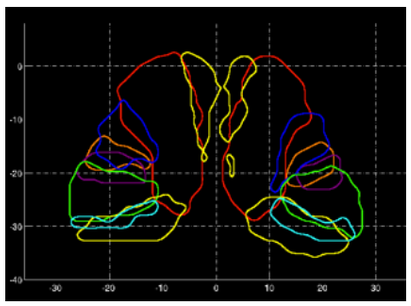
Broca's area
Klein 2007



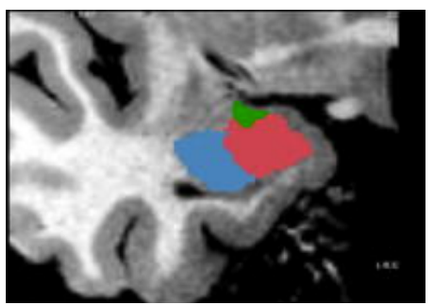
Insular cortex
Cerliani 2012



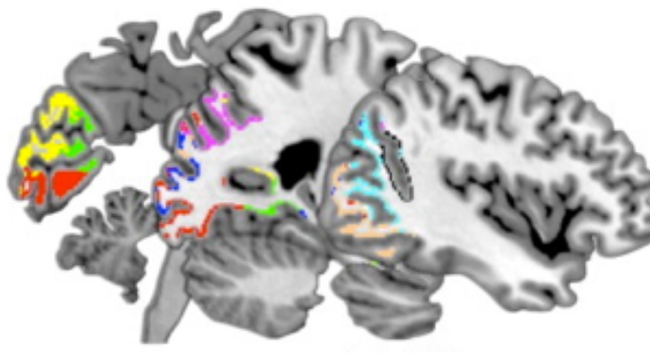
Medial prefrontal
Johansen-Berg 2004



Thalamus
Behrens 2003



Amygdala
Saygin 2011



Occipital cortex
Thiebaut de Schotten 2013