C3GI 2017

Structural and Functional Neural Correlates of Emotional Responses to Music

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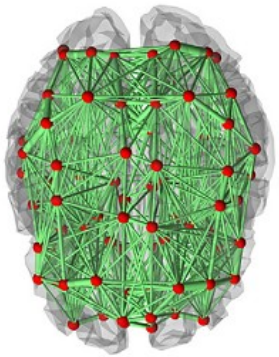
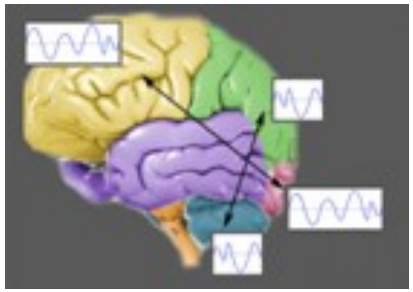
Connectomics

Connectomics

Connectomics (2005) *[Hagmann 2005; Sporns et al., 2005]*: field of neuroscience concerned with the mapping and analysis of connectomes.





- *Connectome*: wiring diagram of the brain.
  - Structural (or anatomical) connectome
  - Functional connectome

- Made possible by the convergence between technological evolution (tract tracing) and avancements in complex networks science.

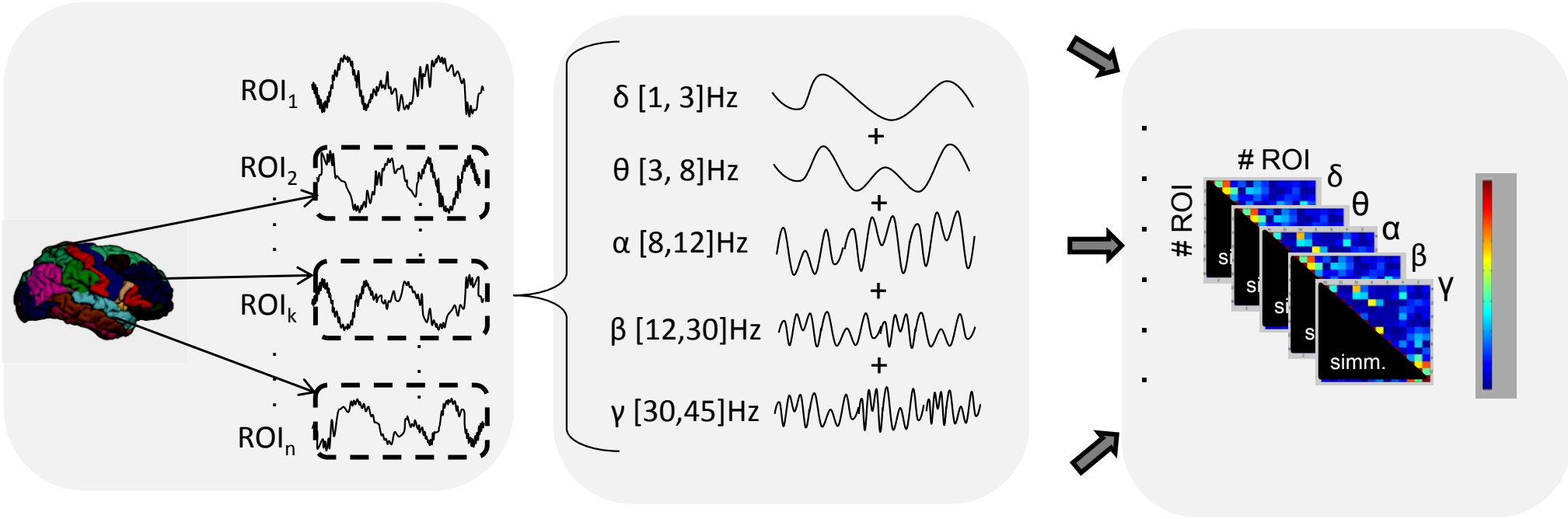
- Graphs allows us to model the human brain connectomes, using graph theory to abstractly define a nervous system as a set of nodes (denoting anatomical regions) and interconnecting edges (denoting structural or functional connections) *[Bullmore and Bassett, 2011]*

- Connectomics of brain disorders: possibility to identify participants at risk.

Functional connectivity (FC)

FC refers to the interaction between the signals from couples of sensors or brain regions. Both in resting state or during task execution.

Brain signals → **Sub-band *filtering*** → ***FC indices*, evaluating interaction** (same band, different ROIs)

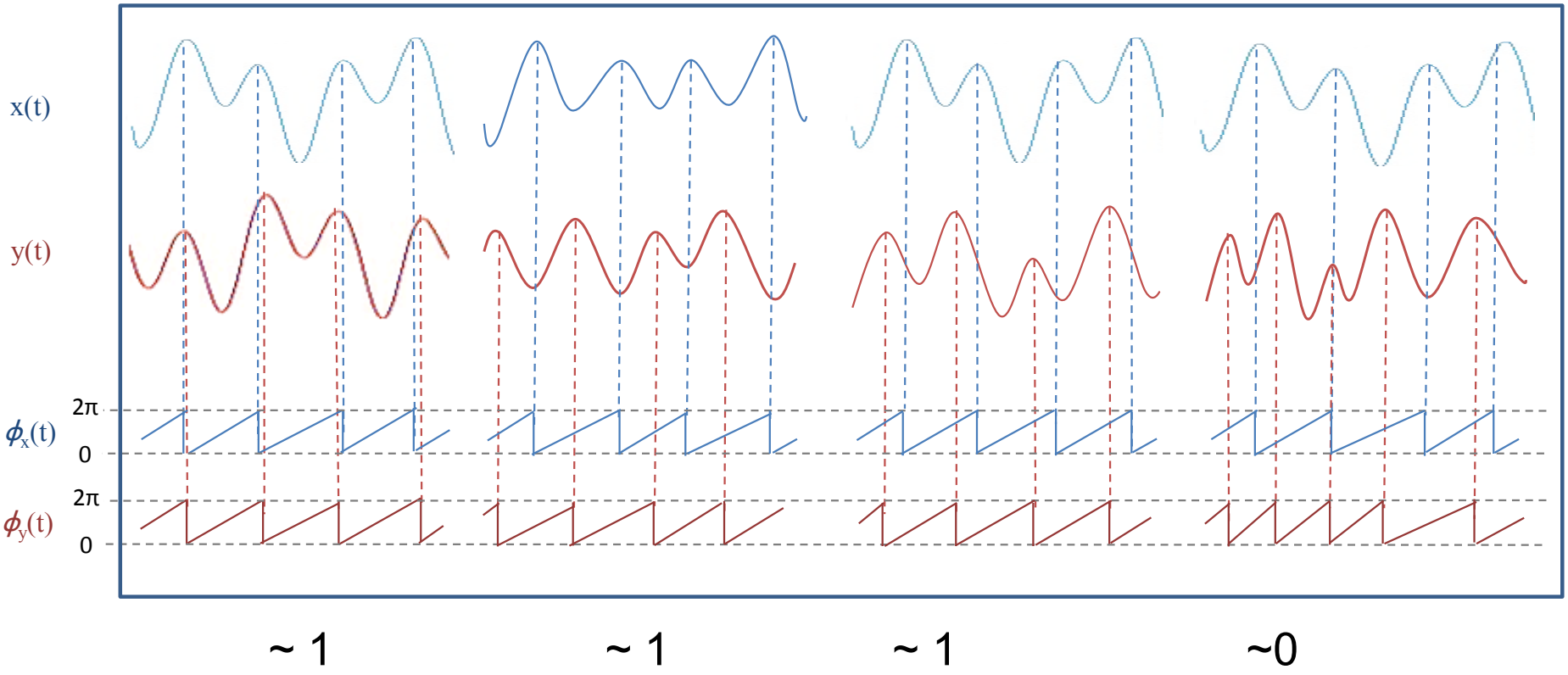


FC analysis:
Phase synchronization indices

PS FC indices: phases of two coupled “oscillators” synchronize, even though their amplitudes may remain uncorrected

Example:
Phase Locking Value (PLV) [0,1] **:** how the **phase** difference between two signals is preserved during the time course? *[Lachaux et al.1999, Niso et al. 2013]*

$$PLV = \left| \left\langle e^{i\Delta\phi_{rel}(t)} \right\rangle \right| = \left| \frac{1}{N} \sum_{n=1}^{N} e^{i\Delta\phi_{rel}(t_n)} \right|$$

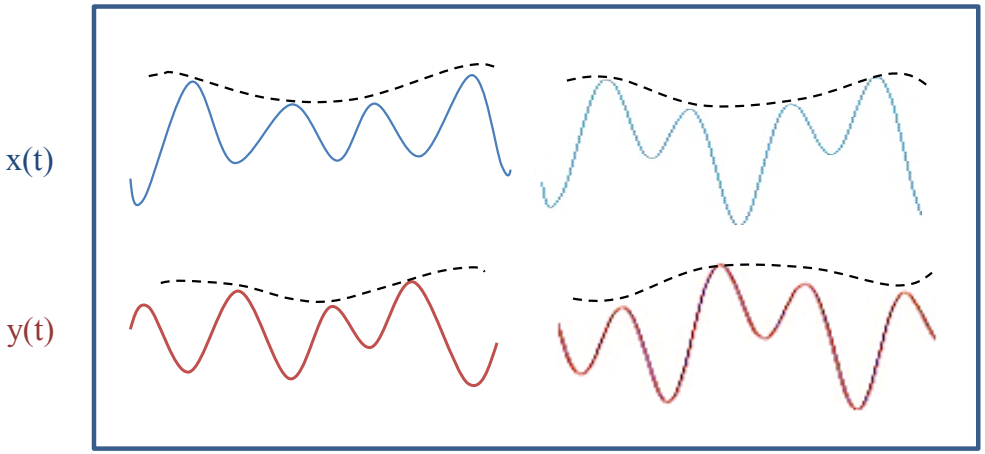


FC analysis:
Amplitude correlation indices

PS FC indices: based on the similarity of the envelopes of a couple of signals.

Example:
Amplitude envelope correlation (AEC) [-1, +1]**:** measures the linear correlation between the **envelopes** of two signals x(t) and y(t)

$$AEC = \frac{Corr\,(H_m(x_r), H_m(y)) + Corr\,(H_m(x), H_m(y_r))}{2}$$



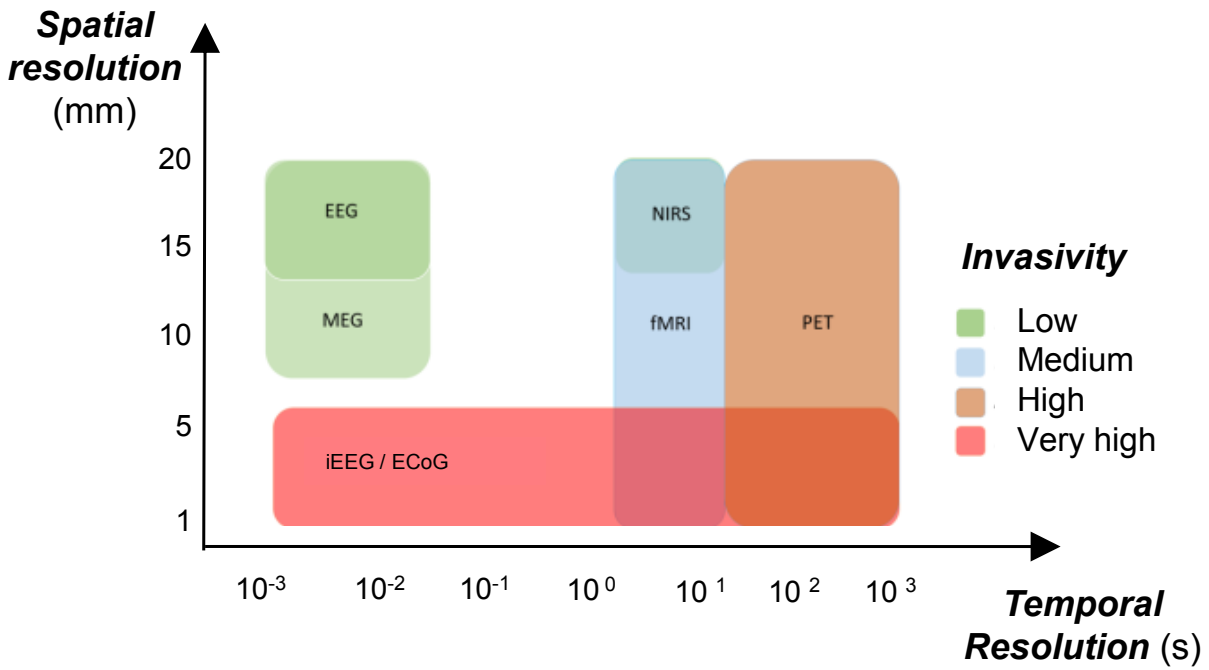
~ +1 ~ -1

Neuroimaging techniques

Functional neuroimaging

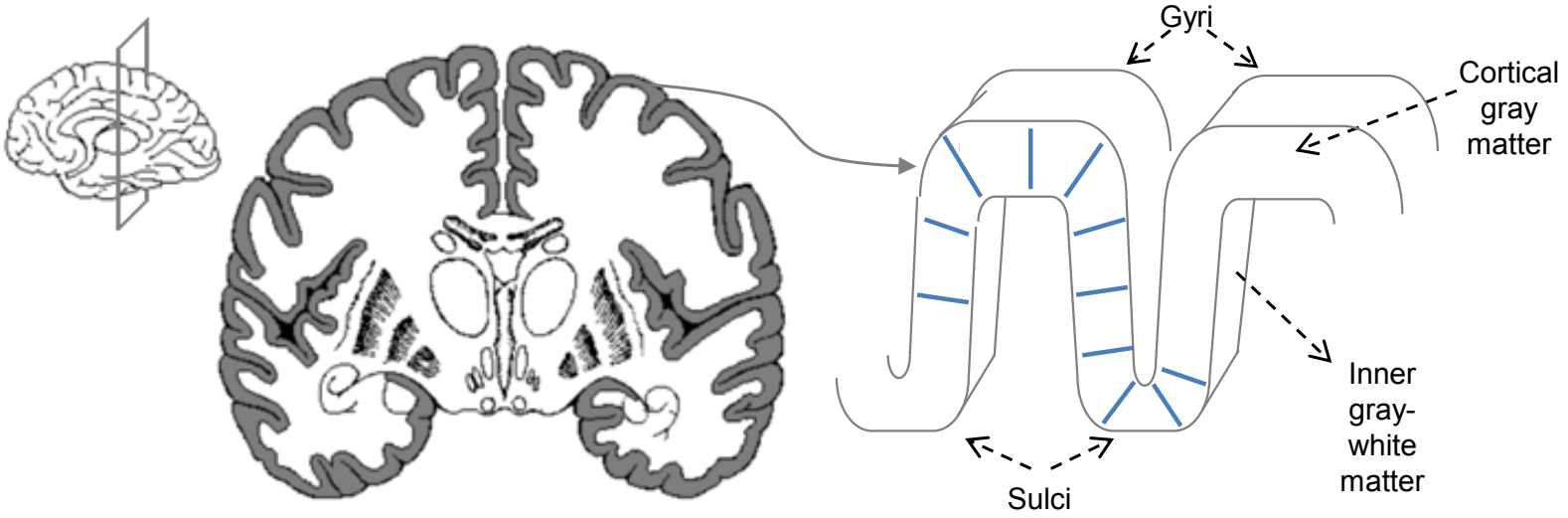
- **fMRI** (functional Magnetic Resonance Imaging).
  - Blood Oxygen Level Dependent – BOLD (indirect measure).
- **PET** (Positron Emission Tomography).
  - use of a radiotracer (invasive)
- **M/EEG** (Magneto-/Electro-EncephaloGraphy):

  - real time
  - non invasive
  - direct measure of brain activity.
- **iEEG/ECoG** (intracranial ElectroEncephaloGraphy, ElectroCorticoGraphy)
  - Intracranial (very invasive)



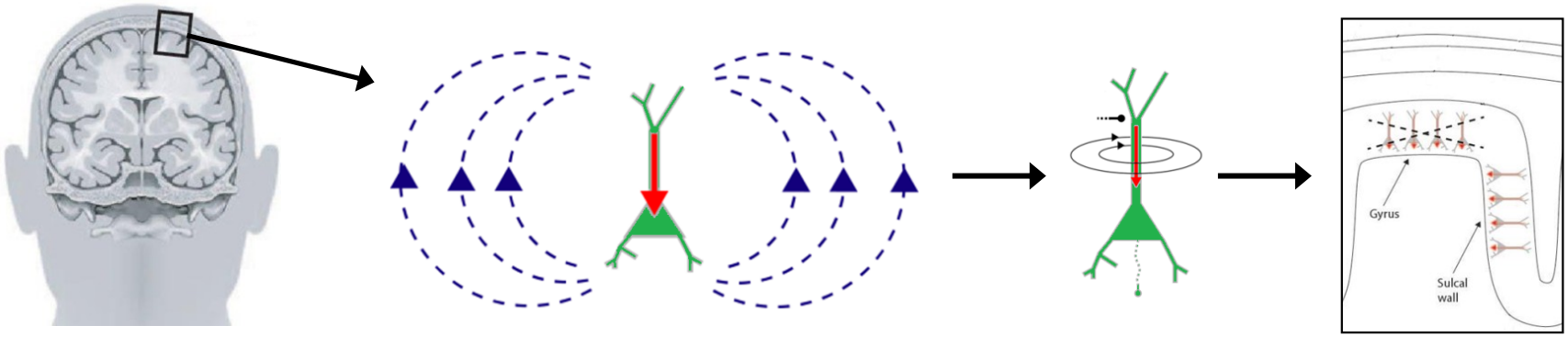
MEG - signal genesis (I)

- Cerebral cortex is the brain's outer layer of neural tissue in mammals.
- Cerebral cortex is dramatically folded (sulci, gyri).
- In cerebral cortex neurons are:
  - connected vertically, and dendrites are typically oriented outward (apical dendrites of pyramidal neurons);
  - organized into 6 main layers;
  - arranged in columnar structures (hierarchic organization of micro-macro columns).

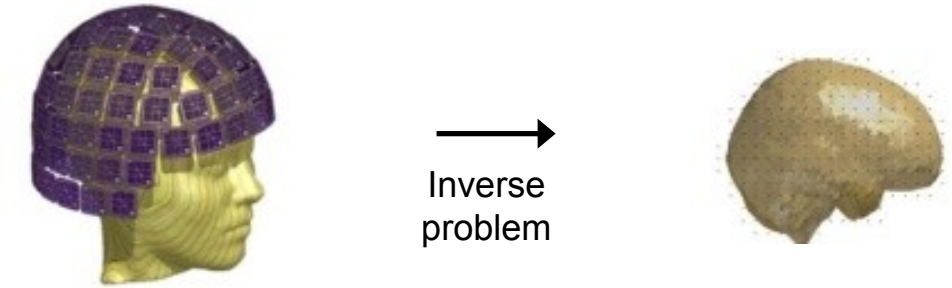


MEG – signal genesis (II)

- MEG
  - Magnetic fields are a consequence of postsynaptic currents generated mainly by pyramidal neurons. They are arranged in the form of a *palisade*, with their main axes parallel to each other, and perpendicular to the cortex.



  - Sensor or source space?



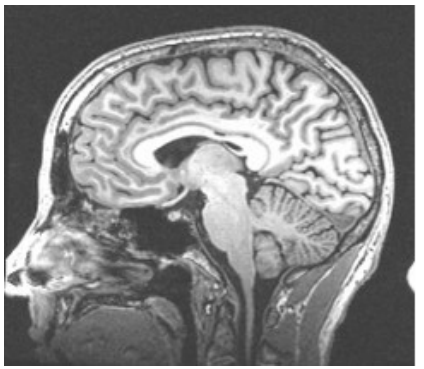
sensor space

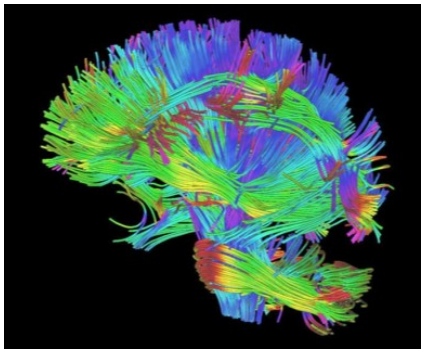
source space

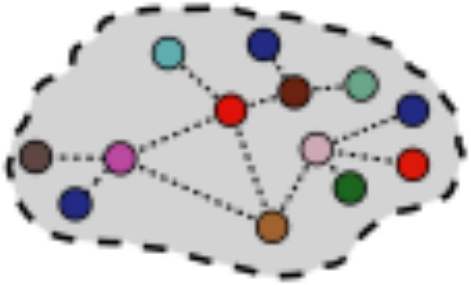
Structural neuroimaging

Structural methods:

- sMRI (structural Magnetic Resonance Imaging): non-invasive technique to qualitatively and quantitatively describe the shape, size, and integrity of gray and white matter structures in the brain
  - DTI: MRI-based technique to map white matter links in the brain, then provide models of brain structural connectivity







Structural links (M_N, M_L, etc.)

Musical anhedonia

Musical anhedonia (*MA*)

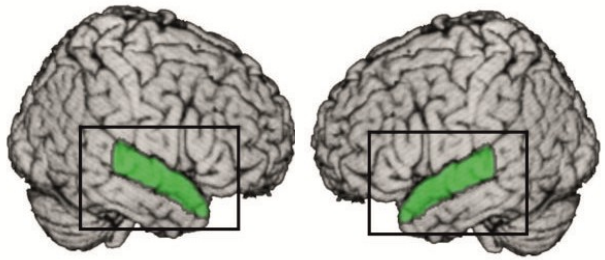
- Musical Anhedonia, or “specific musical anhedonia” indicates the individual's incapacity to enjoy listening to music.

- **Physical anhedonia scale (PAS):** self report scale of general anhedonia.

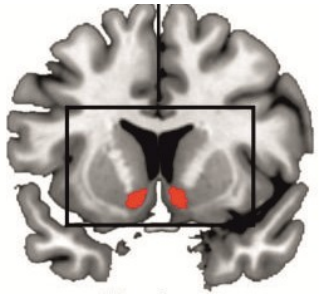
- **Barcelona Music Reward Questionnaire (BMRQ)**: self report scale to assess musical anhedonia. The BMRQ examines five main facets that characterize musical reward experience in individuals: musical seeking, emotion evocation, mood regulation, social reward and sensory-motor.

Functional correlates of *MA*

- Musically-induced pleasure arise from the interaction between *auditory cortical networks* and mesolimbic reward networks (expecially the *nucleus accumbens*), as well as other areas involved in evaluation *[Salimpoor, 2013].*



Lateral views



Coronal section

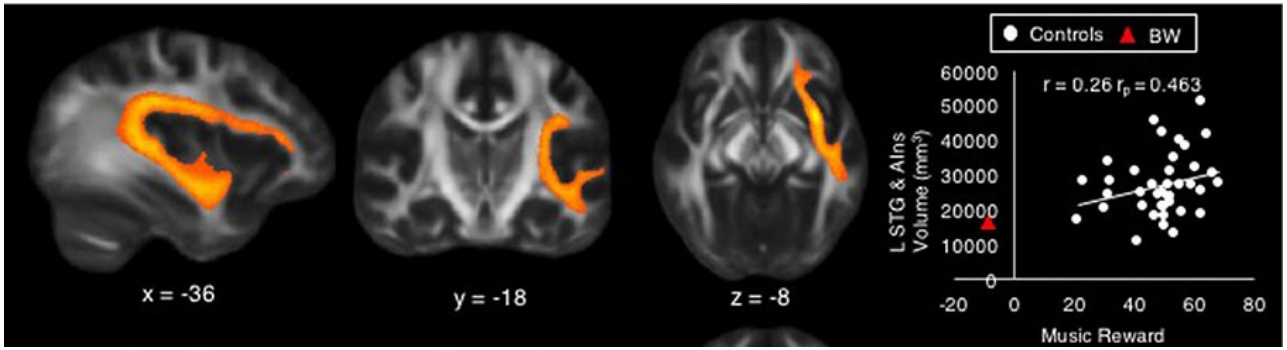
- Altered interactions between auditory cortices and limbic regions, reducing the reward and pleasure induced by music (reduced *liking* experience) *[Mas-Herrero et al., 2014]*

- Musical anhedonia is associated with reductions in the interactions within these two networks *[Martinez-Molina et al., 2016]*

Structural correlates of *MA*

- Structural connectivity between auditory and reward systems reflect individual differences in perceiving reward from music, in a large population.*[Loui, 2017].*

  An extreme case of musical anhedonia presents decreased white-matter volume between left *superior temporal gyrus* and left *Nucleus accumbens*.



MA: recap

Why it is important to study the underpinnings of musical anhedonia:

- a way to understand individual variability in the way the general reward system works;
- this mechanism might help in understanding some disorders involving the reward system, such as addiction and food disorders, or general anhedonia;
- development of therapies for treatment of reward-related disorders, including apathy, depression, and addiction *[Zatorre]*;
- a better understanding of the SC and FC underpinnings of music reward is useful to characterize a correlate of wellbeing in brain structure and function.

Hypotheses validation:

- Optimal *metastability* in pleasure systems would be linked to optimal flow of information and connected emotion processing networks, then could represent the key ingredient in enabling wellbeing *[Kringelbach & Berridge, 2017]*.

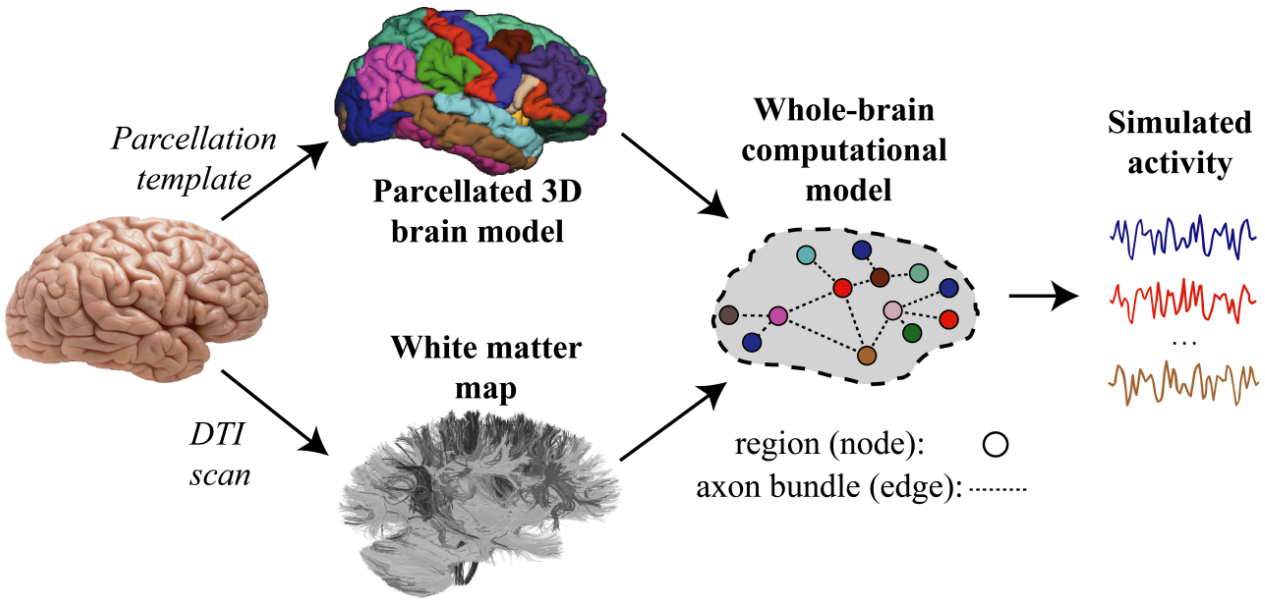
metastability: variability of the states of phase configurations as a function of time, that is, how the synchronization between the different regions fluctuates across time *[Cabral, Kringelbach, et al., 2014]*

Dynamic models of large-scale brain activity in the *connectomics era*

Simulation issues (I)

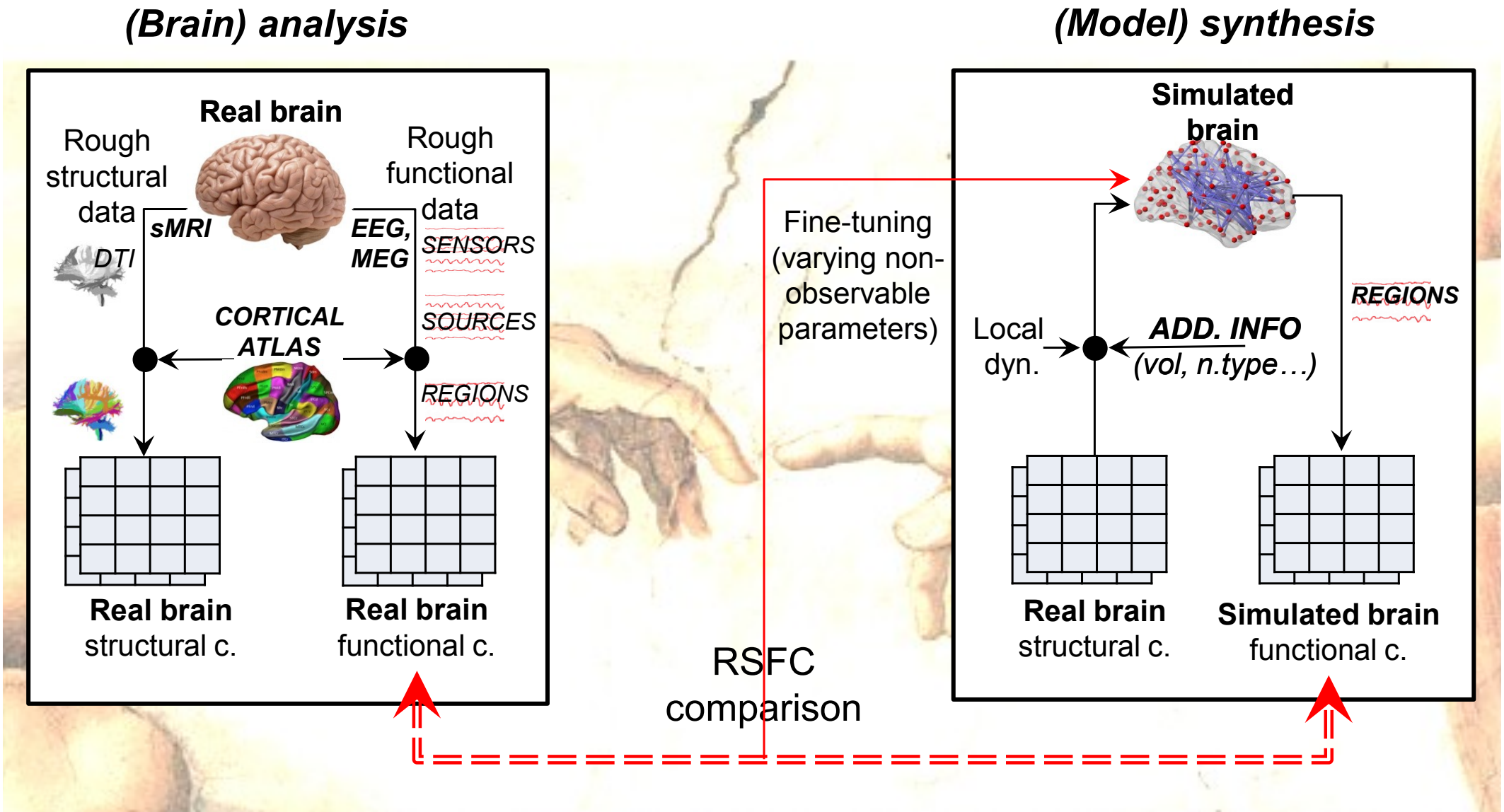
1 - Reproduction of brain structure:

- Links represent axonal pathways or tracts (*white matter*);
- Nodes represent groups of densely interconnected neurons (*gray matter*).

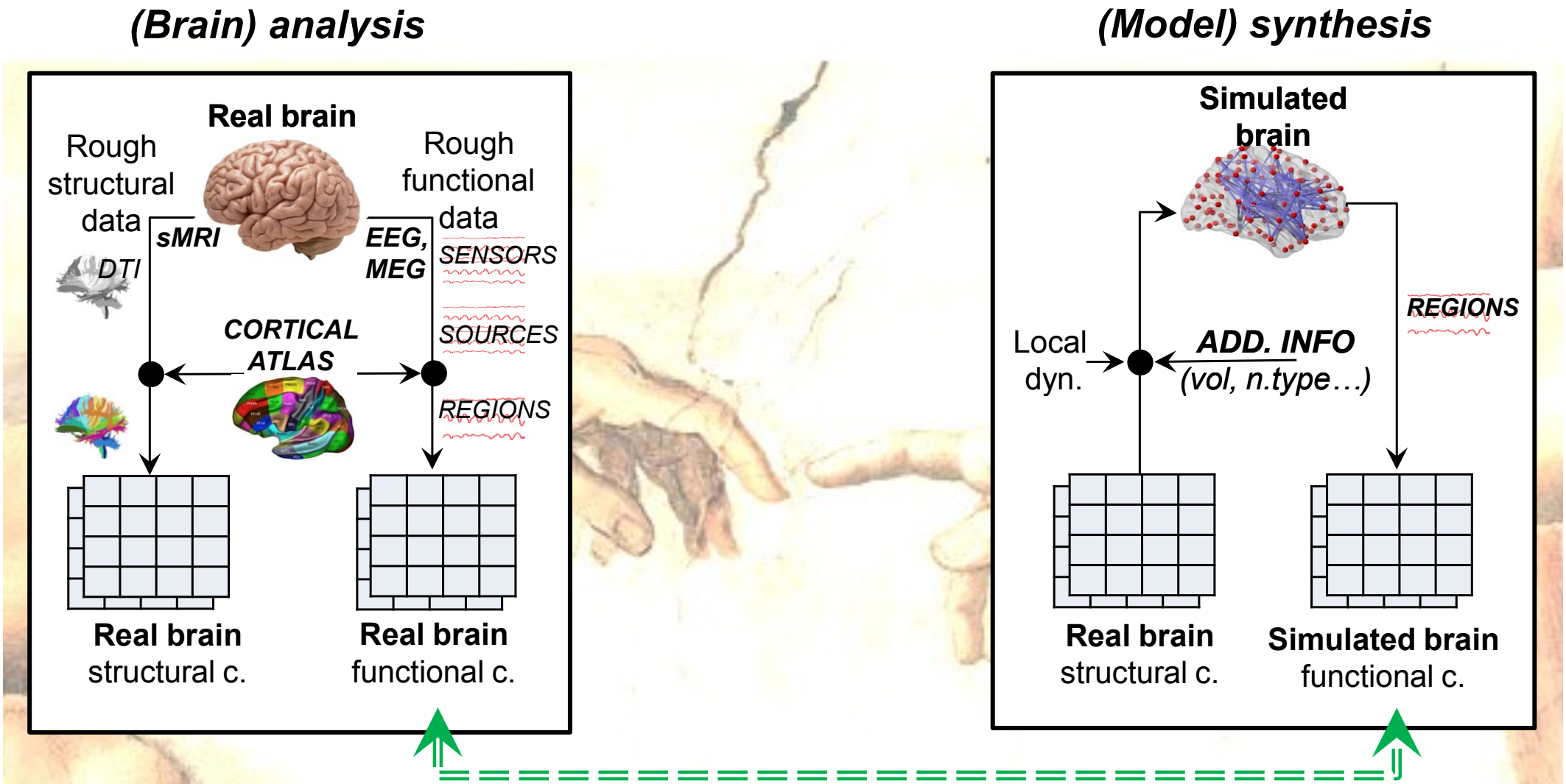


Starting point: predict FC from SC, in resting state.

Simulation issues (II)



Simulation issues (III)



In current models RSFC still doesn't match, but a satisfying correlation degree has been reached.

Future directions (I):

- Large-scale whole brain simulation introducing multi-level diversity:
  - Atlas-based node cardinality (region volumes);
  - Set of neuron parameters for each node (spiking threshold, spike latency, refractory time, etc.) and edge (length and weight distributions).

Conclusion

- Lack of MEG studies of musical anhedonia. MEG can provide an extended view with respect to MRI.

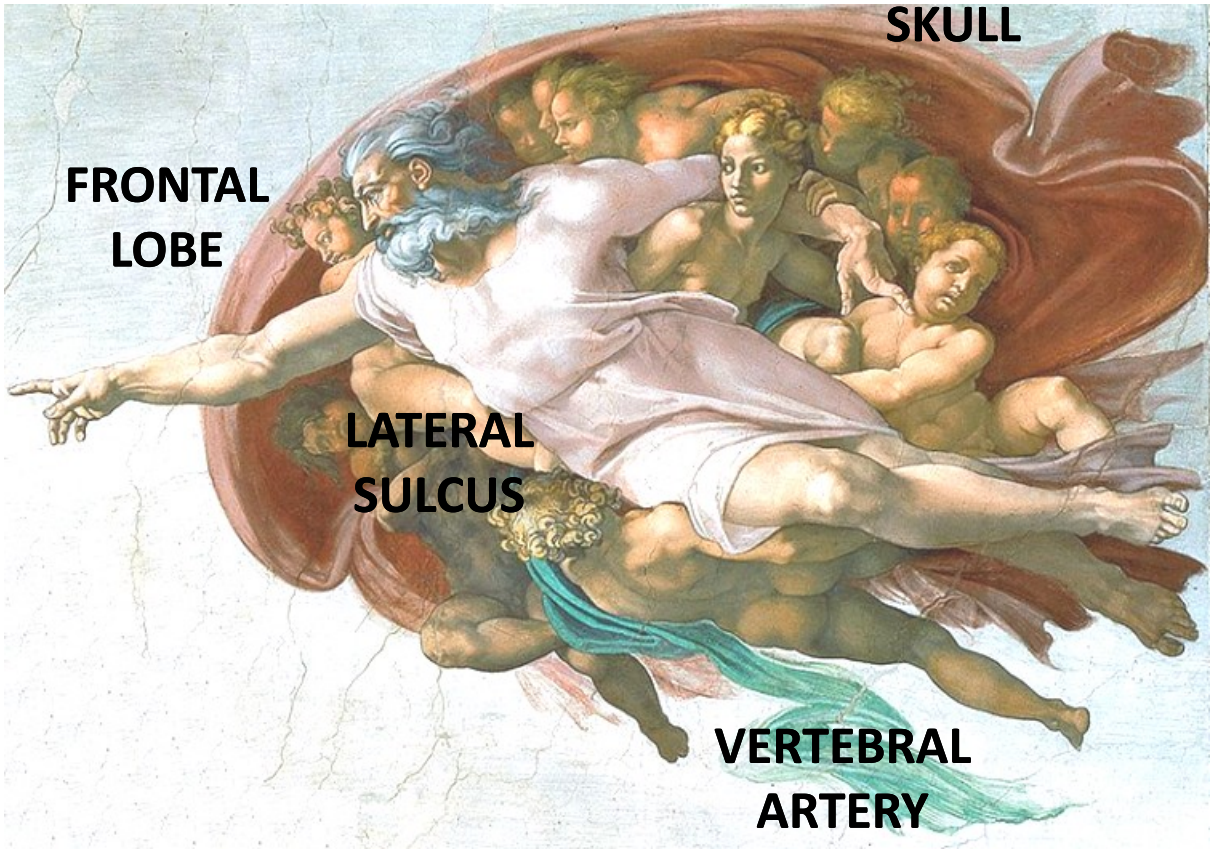
- A spiking network model of MA subject as test-bench:
  - to study functional regimes (metastability) in reward system with respect to the modulaton of the structural parameter identified from recent literature;
  - to shed light on of function and dysfunction of the reward system [Zatorre] : characterize a correlate of wellbeing in brain structure and function.

Research group(s)

Laboratory of Cognitive and Computational Neuroscience, CTB.
Universidad Politecnica/Universidad Complutense, Madrid

ELTlab group. University of Rome, “Tor Vergata”

Thanks for your attention!



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