



scientifica

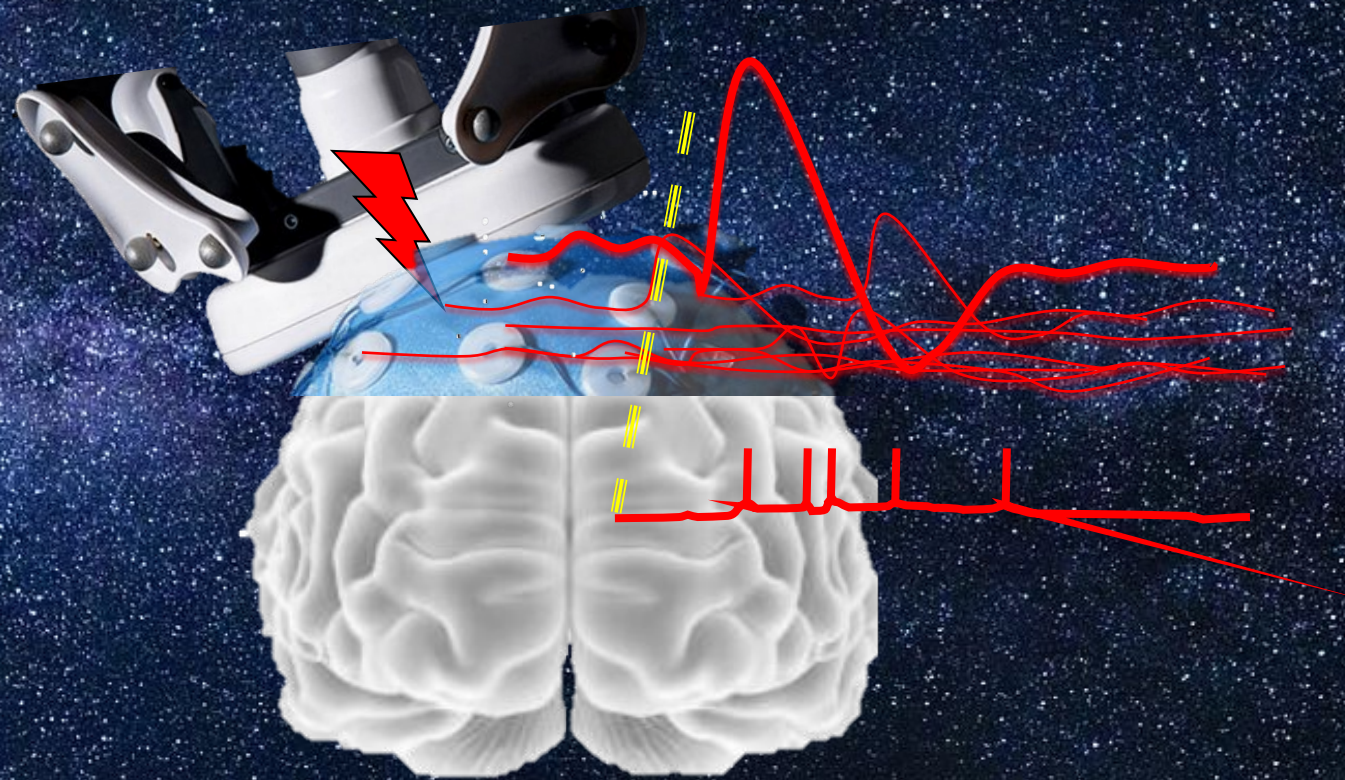
presenta le LEZIONI DI SCIENZA
gli eventi di approfondimento sulle materie scientifiche

 **MONDADORI**
EDUCATION

The background features several circular elements with diagonal white stripes. The top-left circle shows a green forest. The top-middle circle shows a blue sky with a sun. The top-right circle shows a grey, rocky or snowy landscape. The bottom-left circle shows a yellow and orange sunset. The bottom-middle circle shows a red jellyfish. The bottom-right circle shows a red jellyfish.

Alla ricerca della coscienza

Marcello Massimini
MD, PhD













"We will never know how the water of the physical brain is turned into the wine of consciousness"



Coma



Coma

► Communication



Coma ➔ Vegetative State

➔ Communication

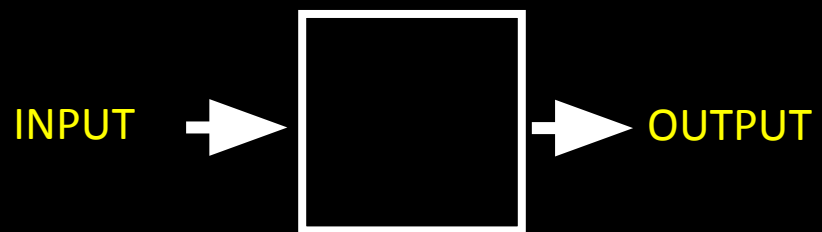


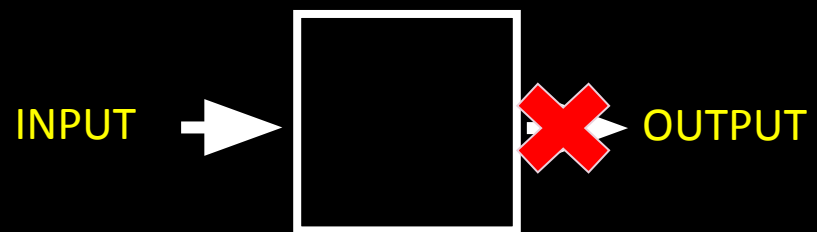
Coma ▶ Vegetative State ▶ Minimally Conscious State ▶ Communication

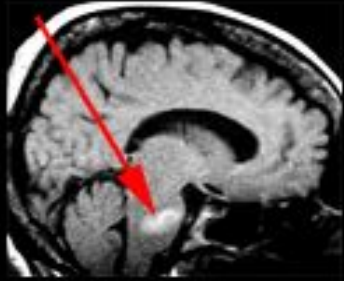


40% error!

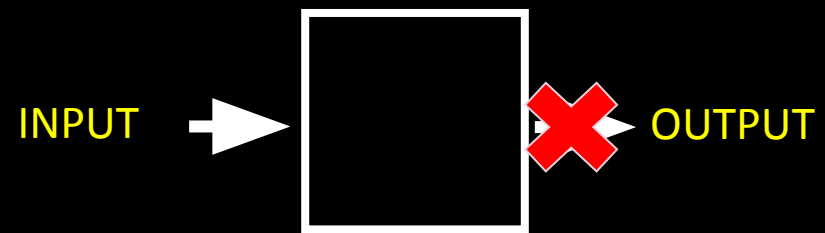






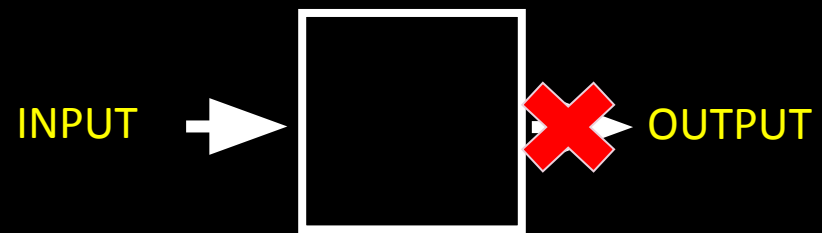


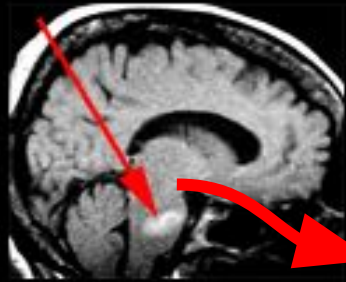
Locked-in Syndrome





Locked-in Syndrome

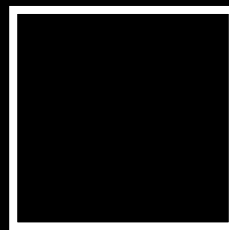




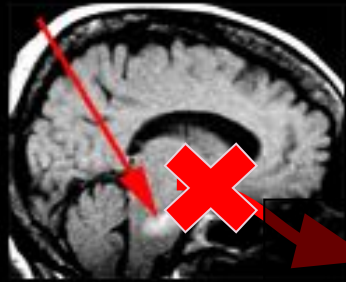
Locked-in Syndrome



INPUT



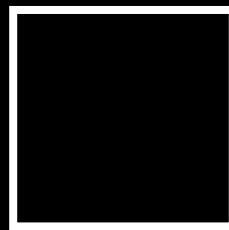
OUTPUT



Total Locked-in Syndrome

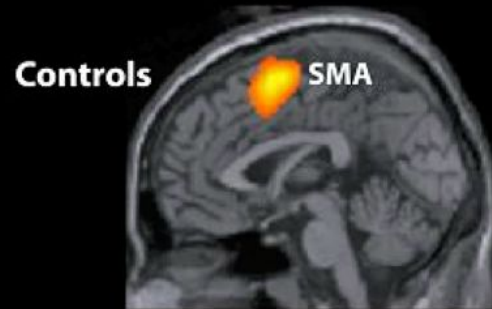


INPUT

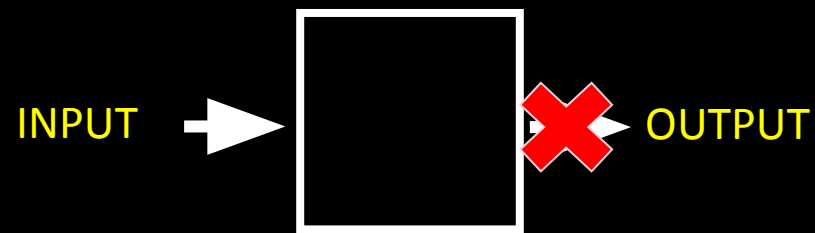
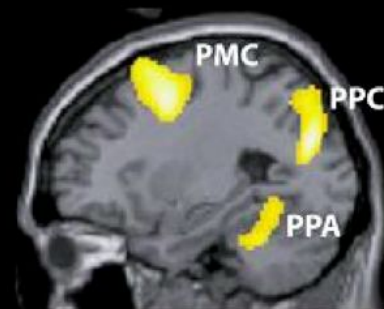


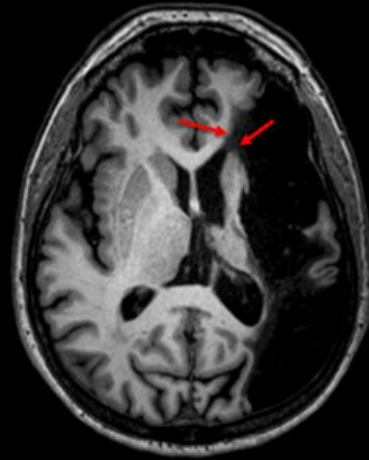
OUTPUT

Tennis Imagery

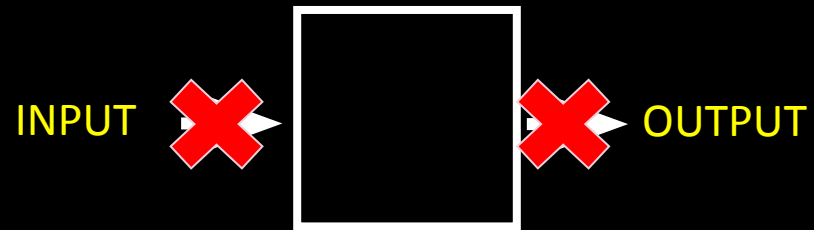


Spatial Navigation Imagery



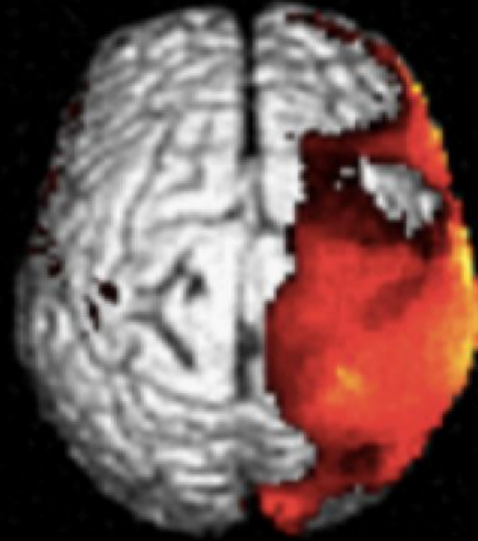


left



ISLANDS of AWARENESS?

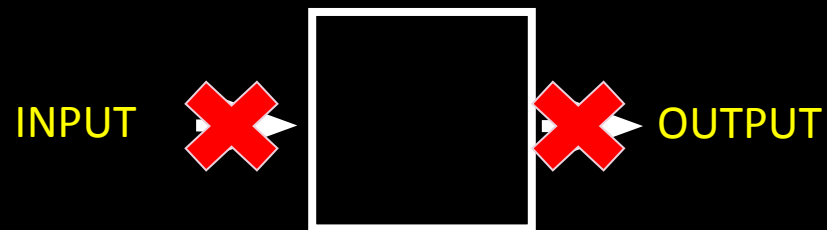
Bayne, Seth, Massimini *Trends in Neuroscience* 2020



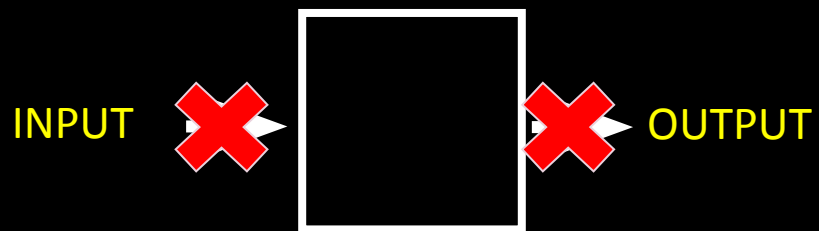
In the US:

50,000 unresponsive patients (VS)
300,000 minimally responsive (MCS)

All at risk of misdiagnosis!



Majerus et al., 2005
Laureys and Schiff 2012



A brain-based index independent of sensory processing, executive and motor functions





SOUL HAS WEIGHT, PHYSICIAN THINKS

Dr. Macdougall of Haverhill Tells
of Experiments at
Death.

LOSS TO BODY RECORDED

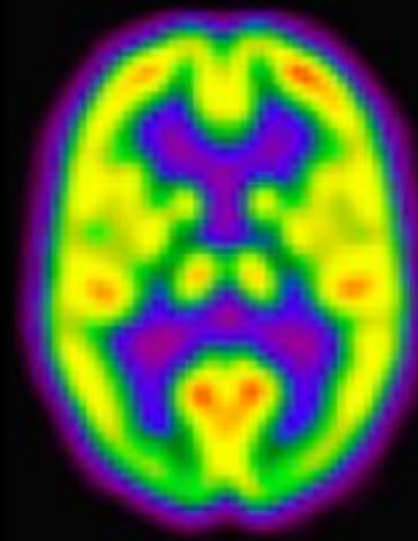
Scales Showed an Ounce Gone in One
Case, He Says—Four Other
Doctors Present.

Special to The New York Times.

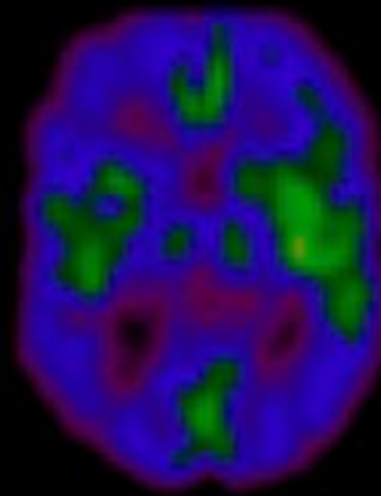
BOSTON, March 10.—That the human soul has a definite weight, which can be determined when it passes from the body, is the belief of Dr. Duncan Macdougall, a reputable physician of Haverhill. He is at the head of a Research Society which for six years has been experimenting in this field. With him, he says, have been associated four other physicians.



CONSCIOUS

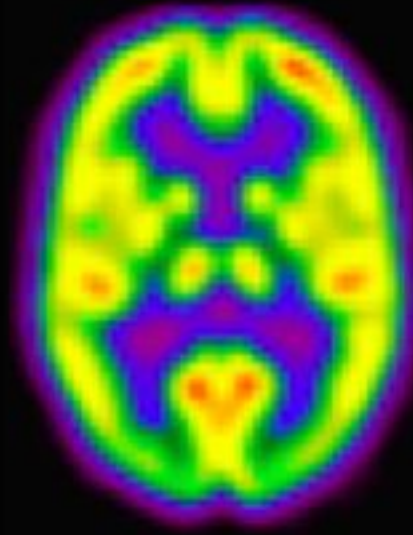


VEGETATIVE

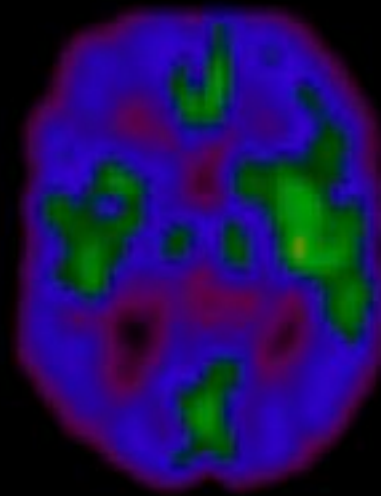




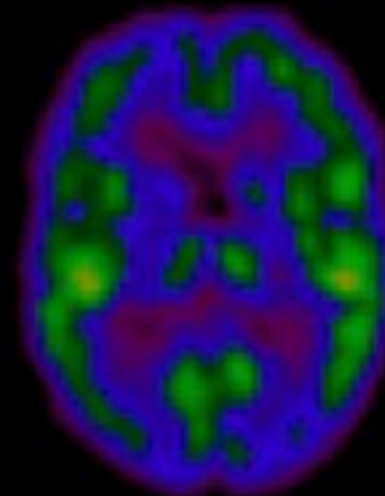
CONSCIOUS



VEGETATIVE



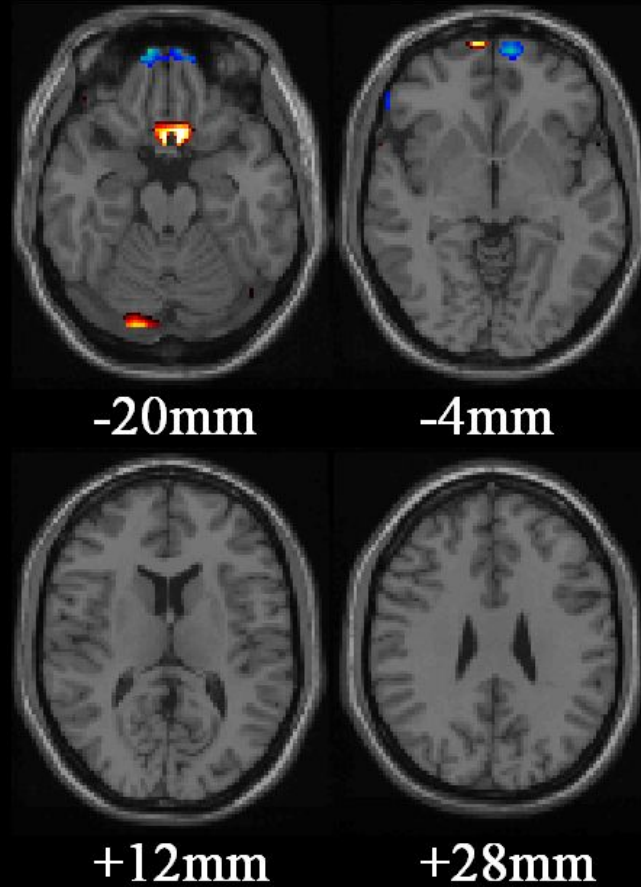
RECOVERY





absence seizure

-20s





BCILab



The Blue Brain Project



The Blue Brain Project





The Blue Brain Project



The Blue Brain Project

Fundamental paradoxes, still unsolved:

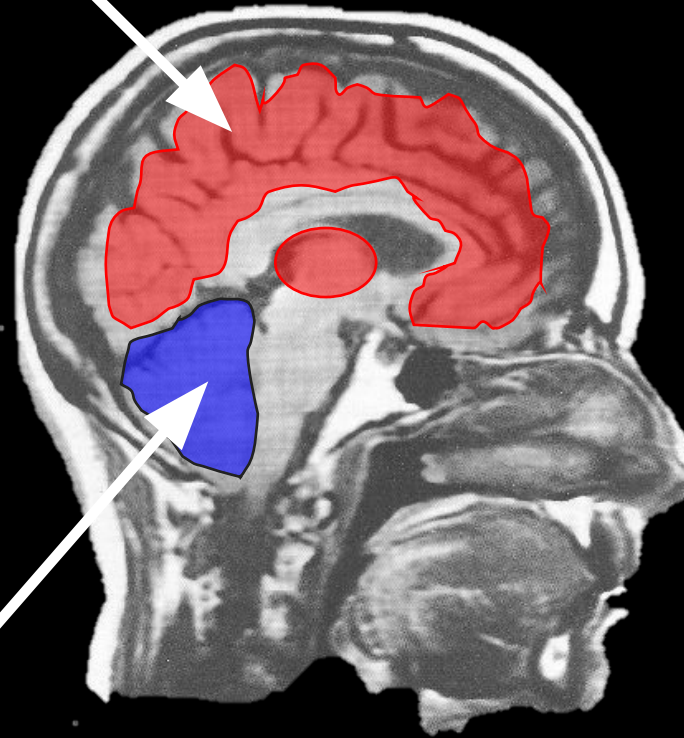
Fundamental paradoxes, still unsolved: **wake vs sleep**



Steriade et al., *J. Neurophysiol.* 2001

Fundamental paradoxes, still unsolved: **cerebral cortex vs cerebellum**

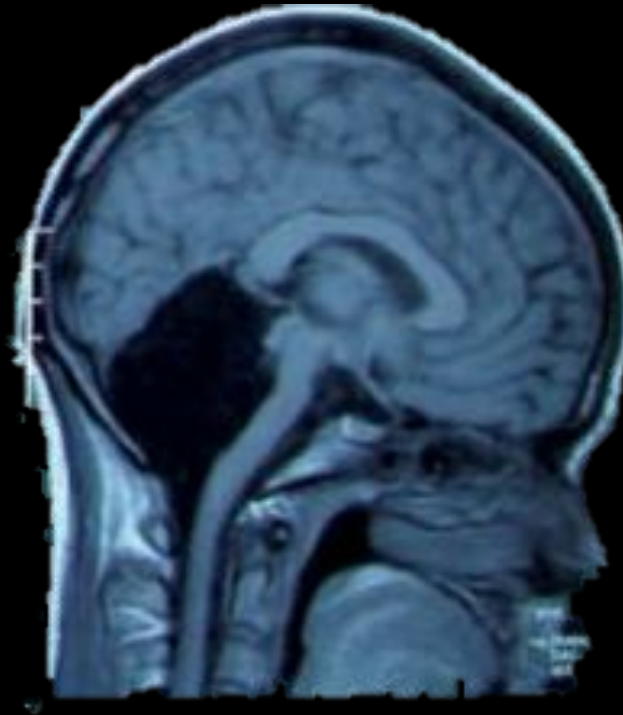
Thalamocortical System = 20 billion neurons



*Cerebellum = 80 billion neurons
!!!!!!!*

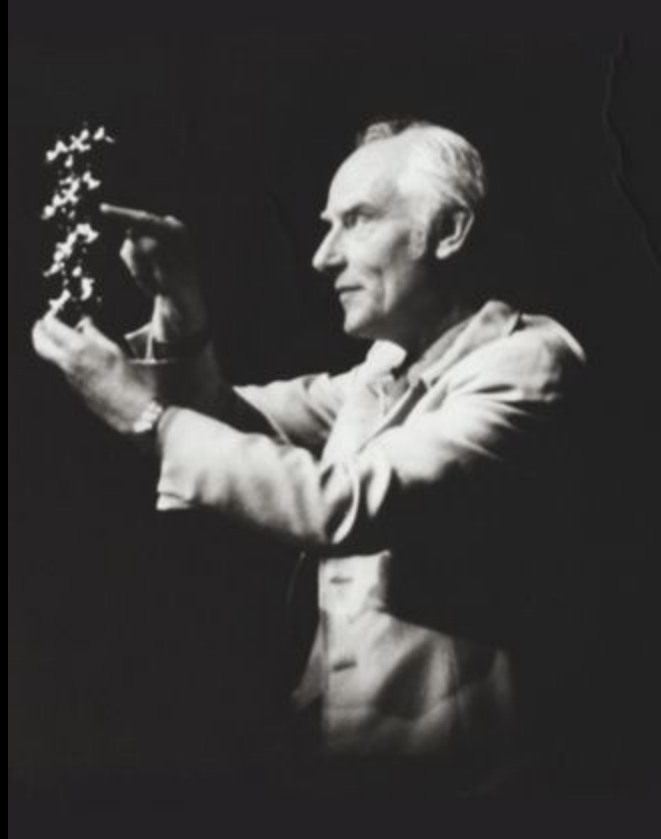
Fundamental paradoxes, still unsolved: cerebral cortex vs cerebellum

*Life without a
cerebellum*



Yu et al., Brain 2015

A theoretical approach to measuring consciousness



The Information Integration Theory of Consciousness (IITC)

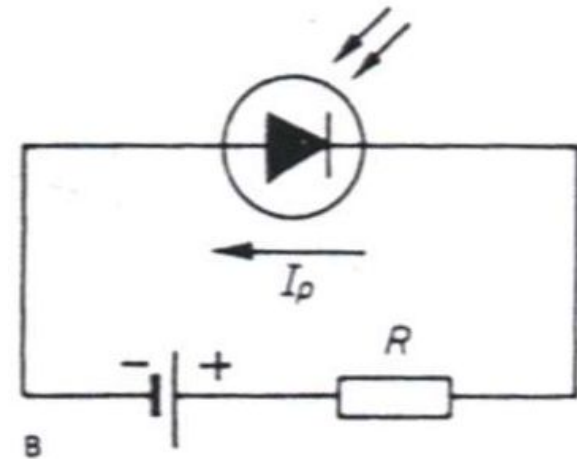
***A physical system is conscious to the extent
that it **integrates information*****

G. Tononi, G. Edelman, *Science*, 1998.

G. Tononi, M. Boly, M Massimini, C Koch, *Nature Review Neuroscience* 2016

A thought experiment...





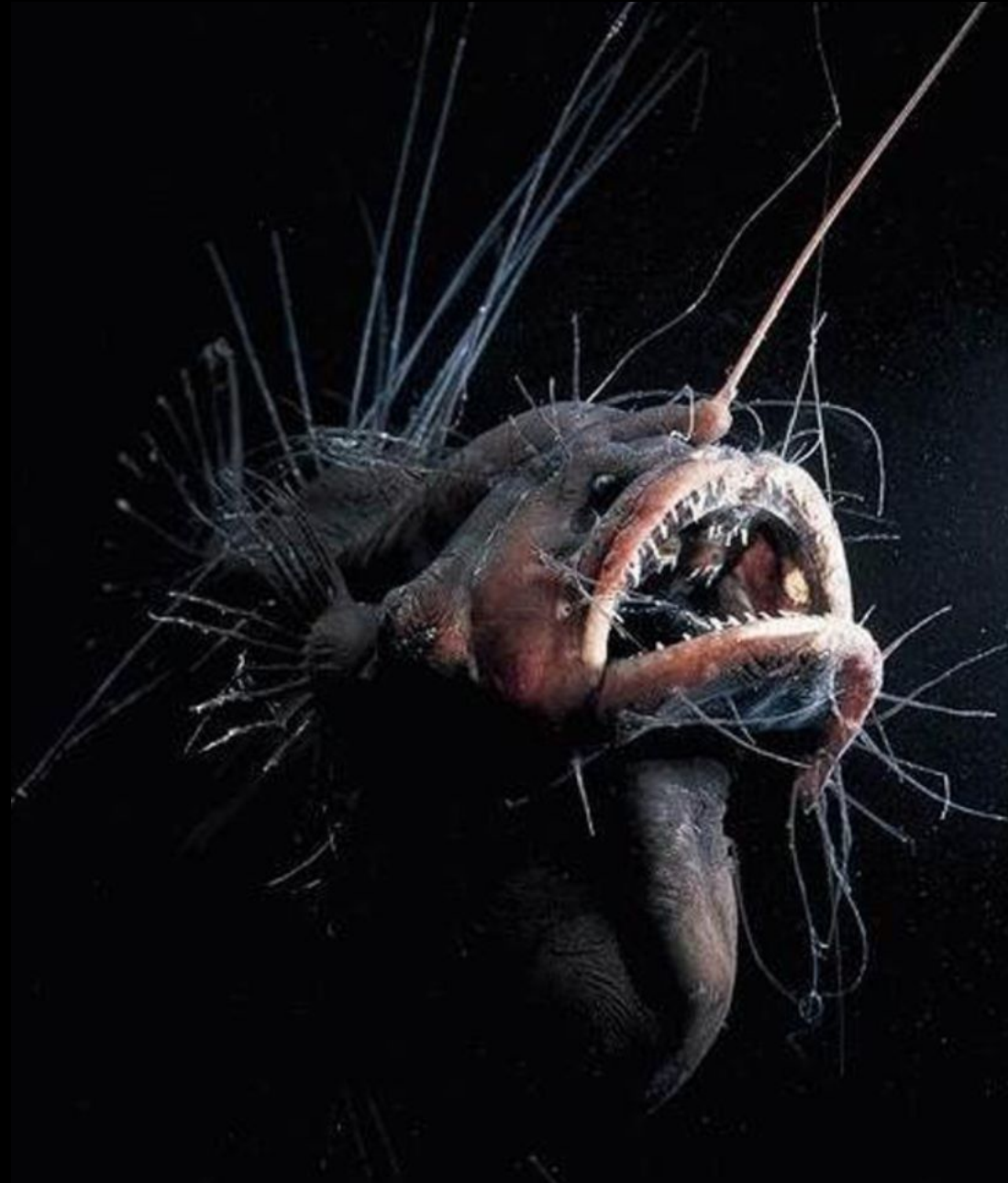
























light
dark



$$\log_2(2) = 1 \text{ bit}$$





light
dark



$$\log_2(2^{1.000.000.000}) = 1.000.000.000 \text{ bit}$$

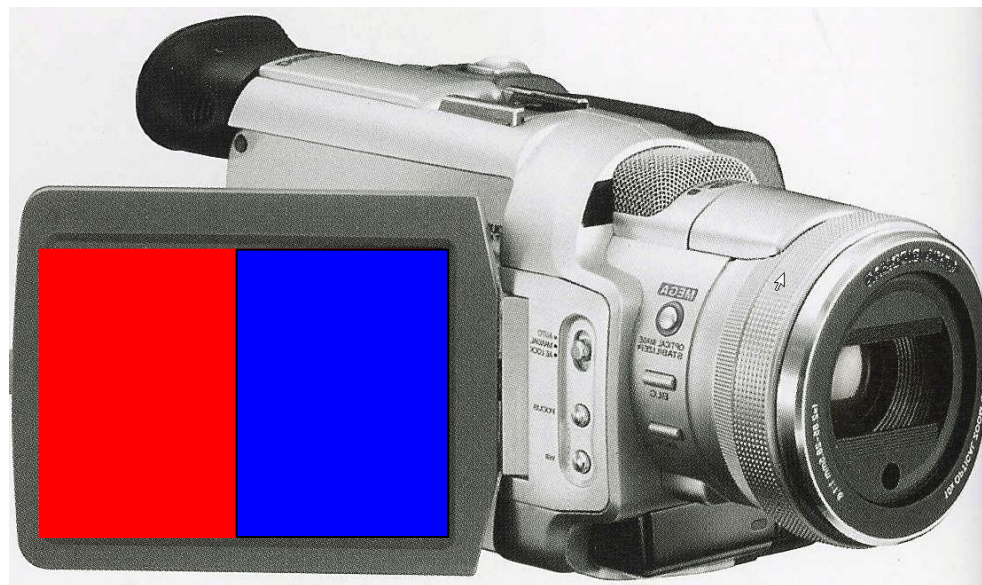












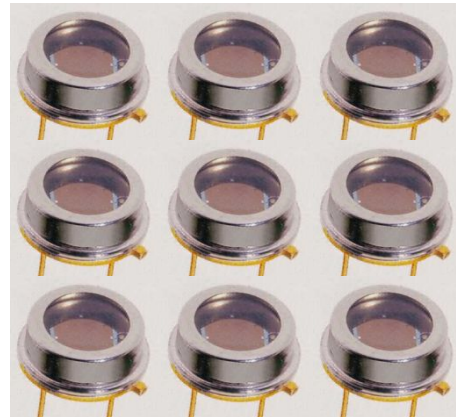
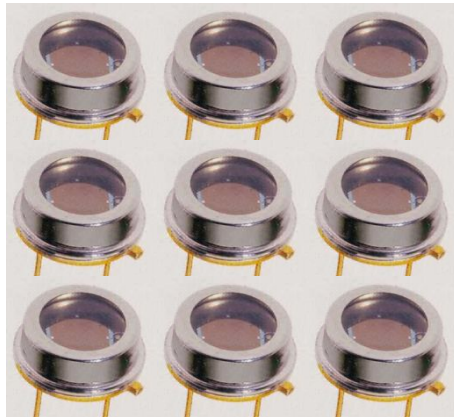
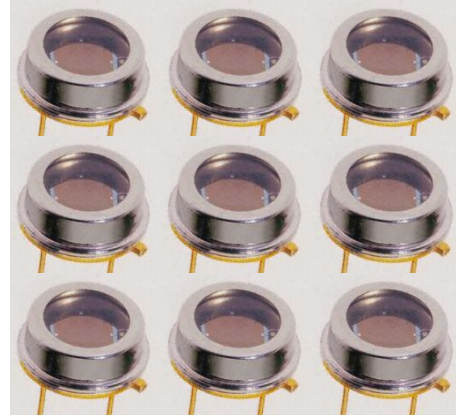
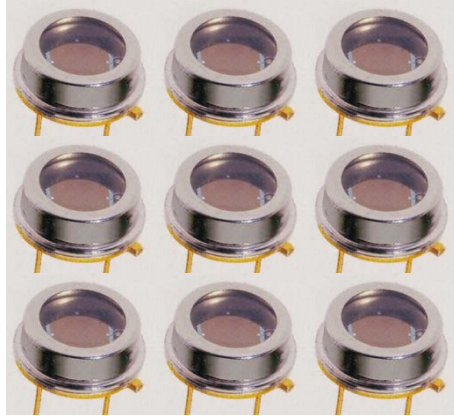


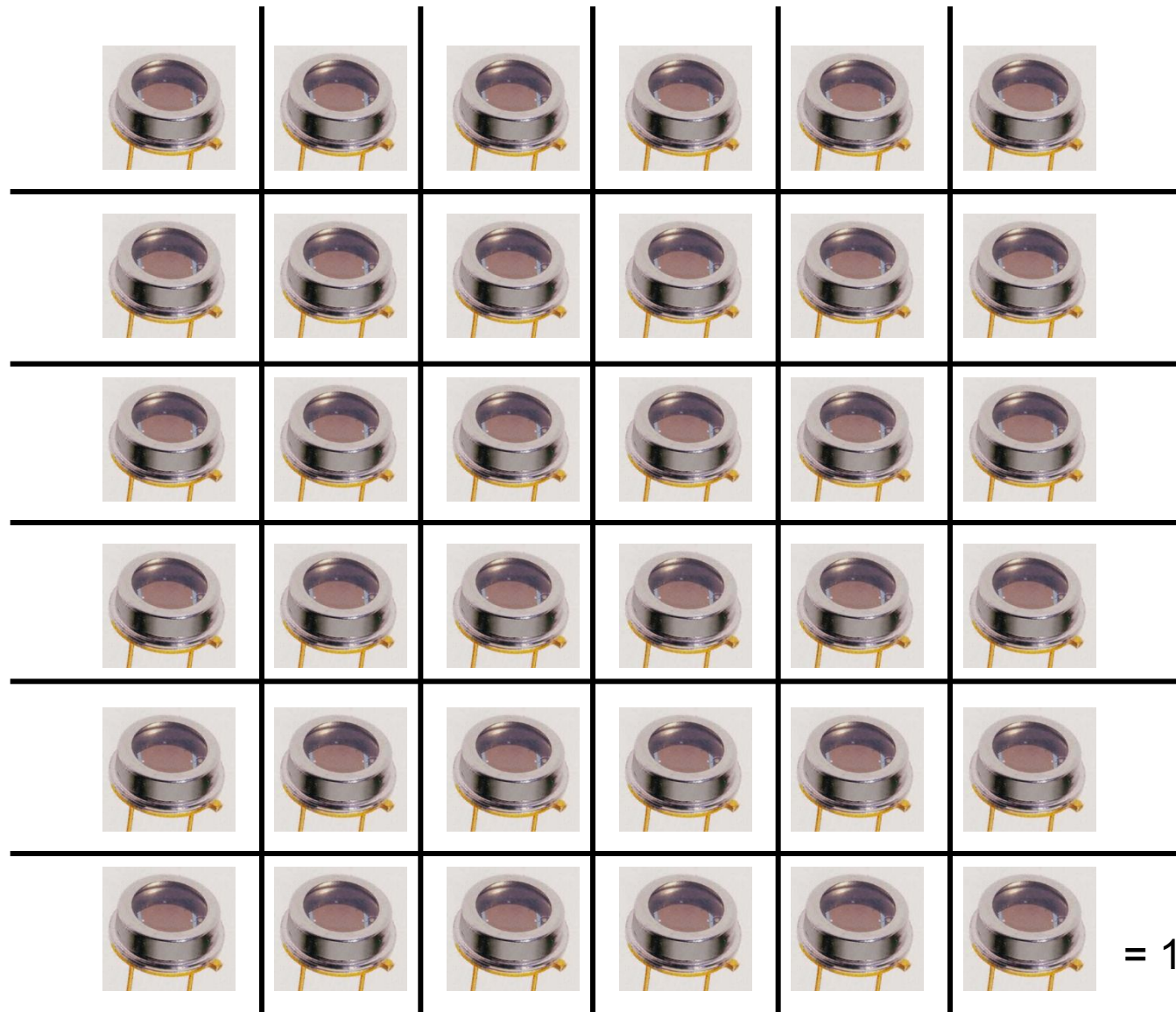








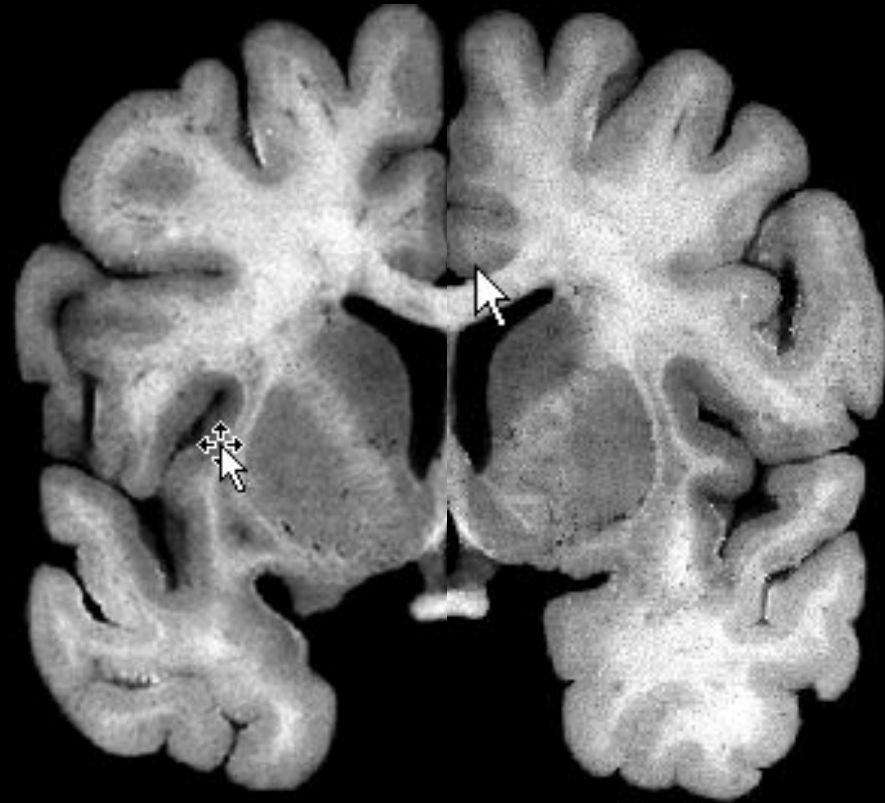




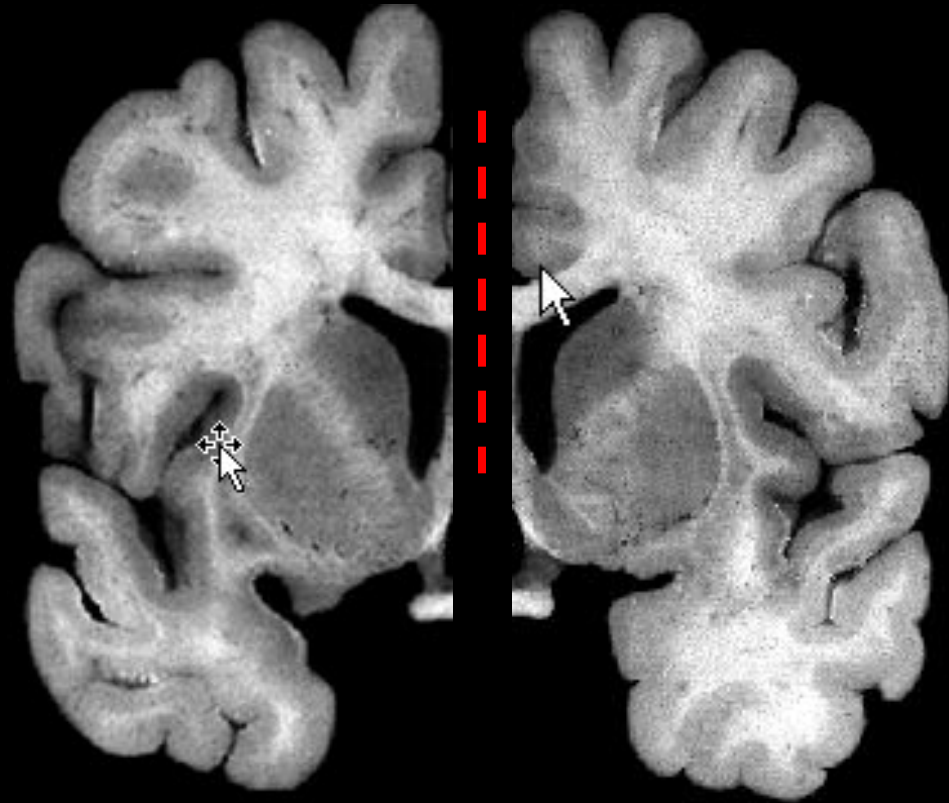
= 1 bit

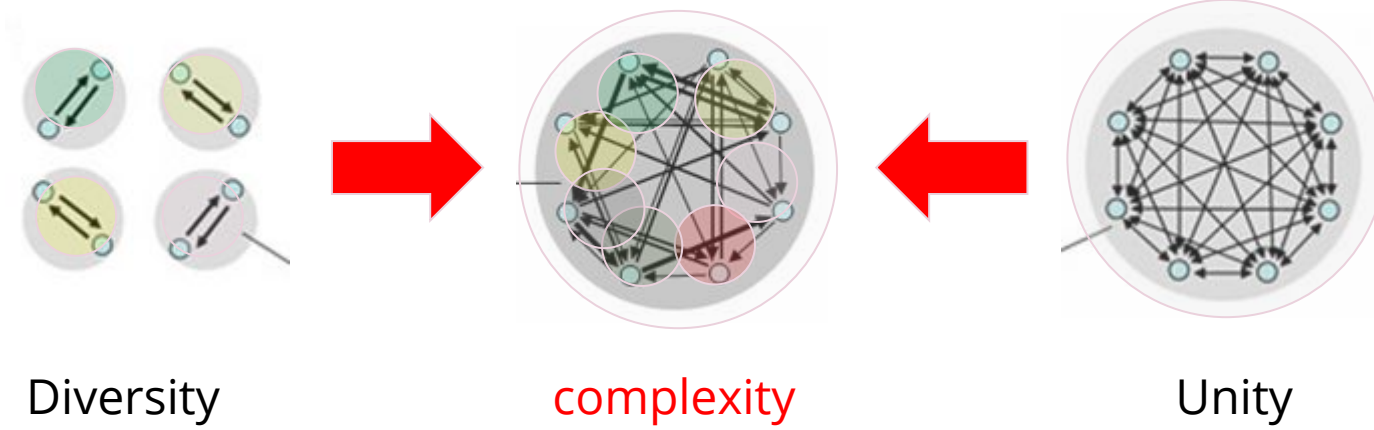
Try....

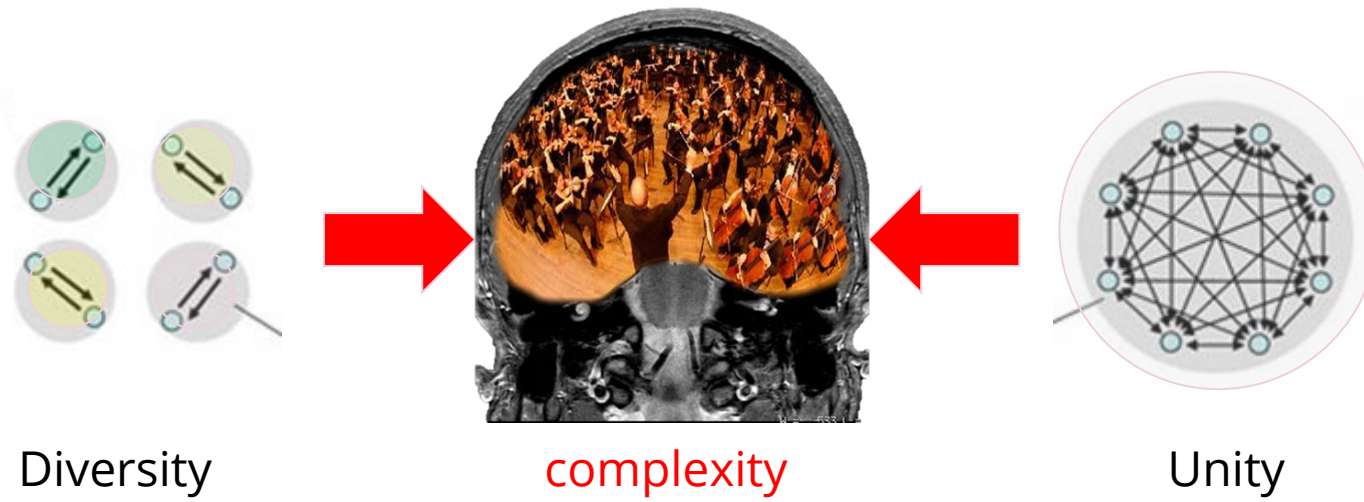




Split Brain: due coscienze nello stesso cranio





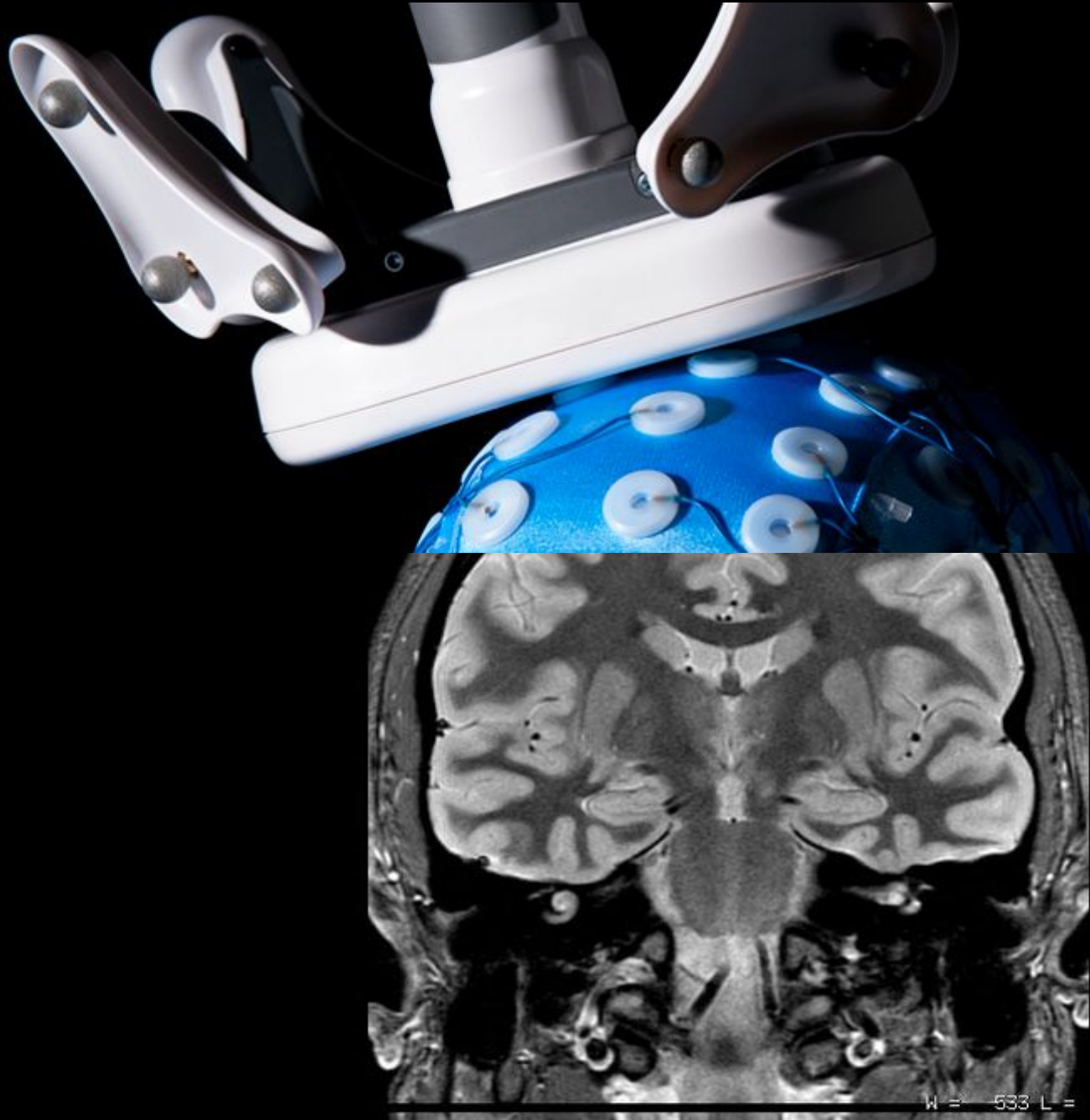


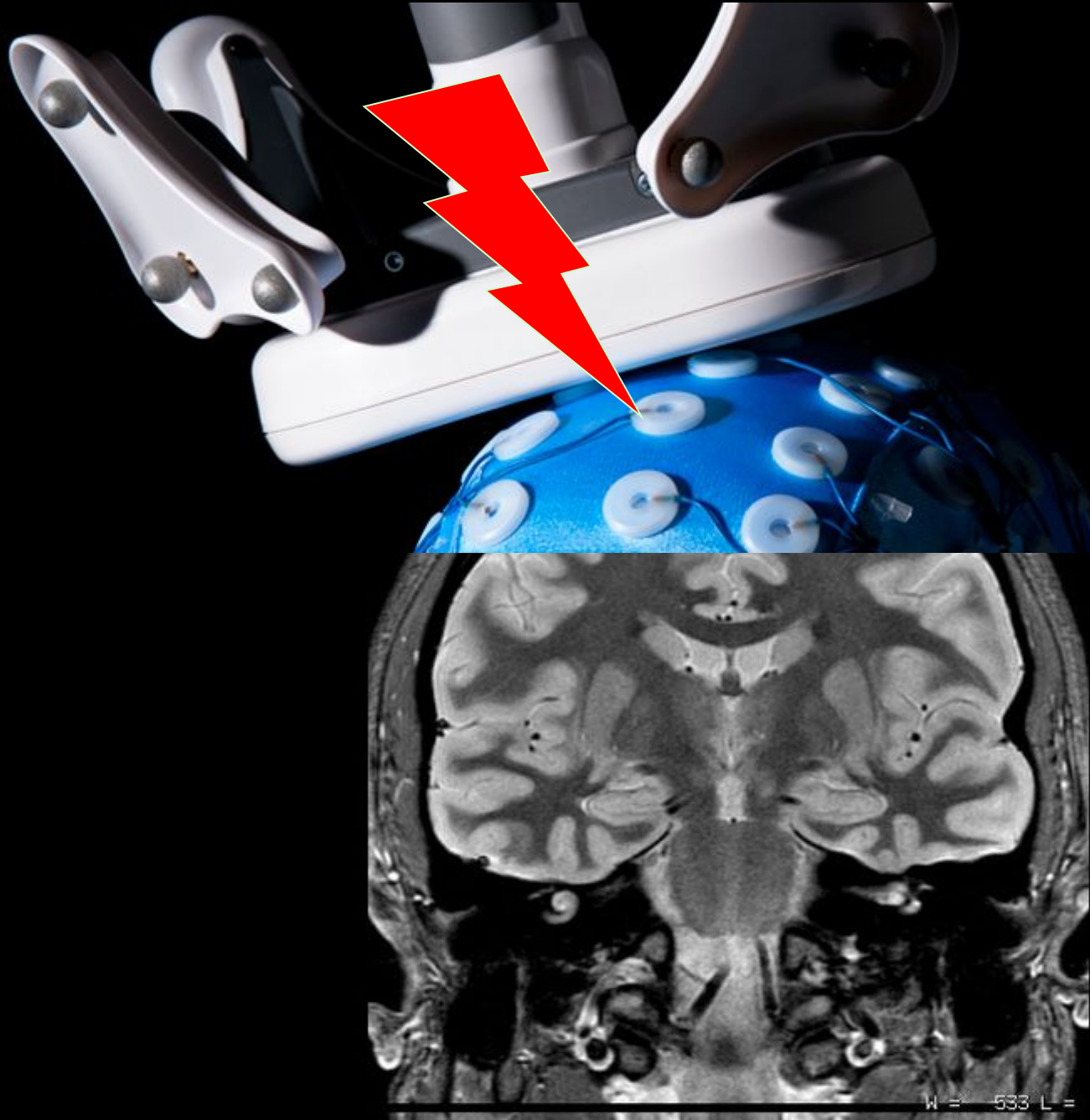


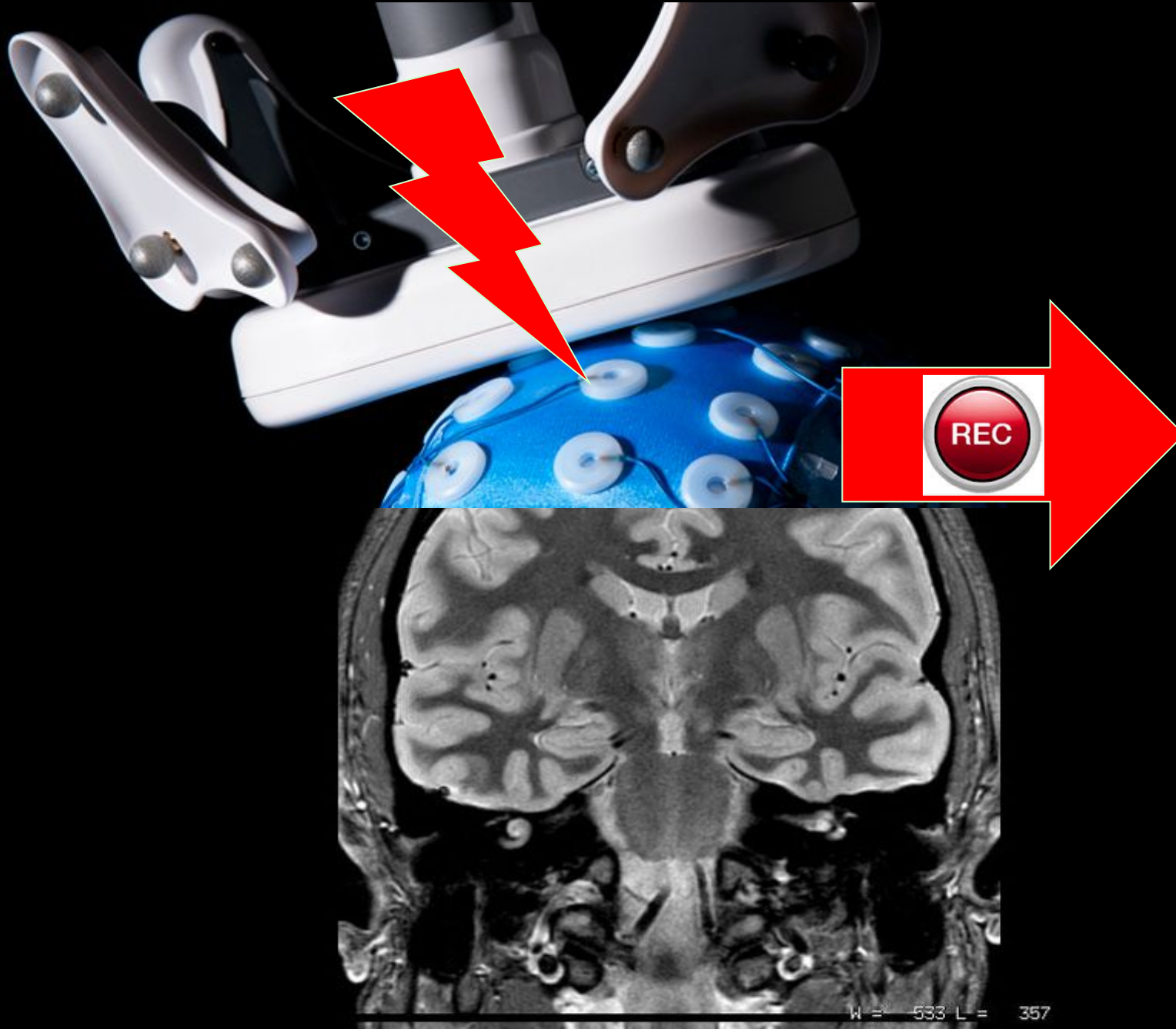
W = 633 L = 367



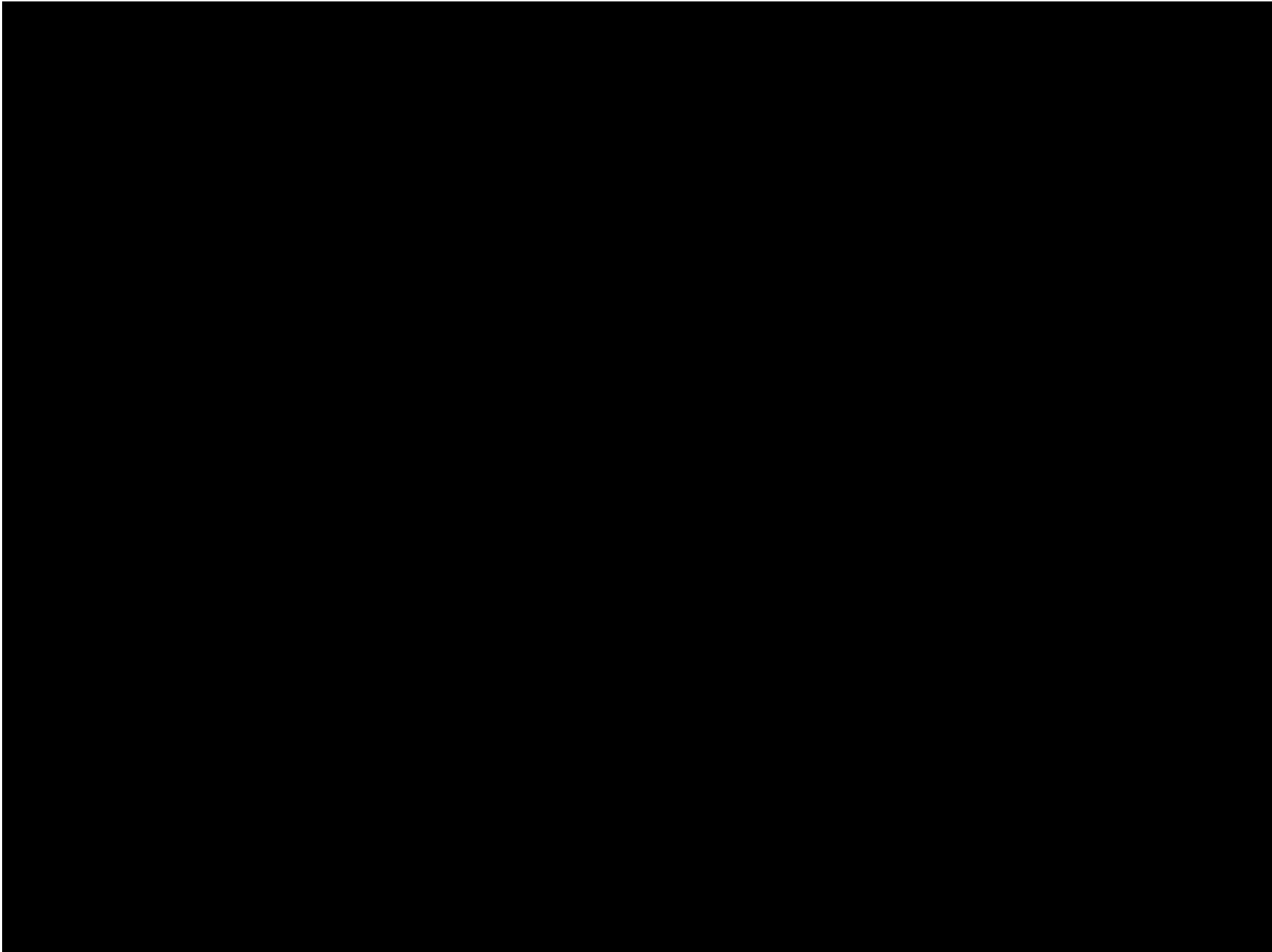




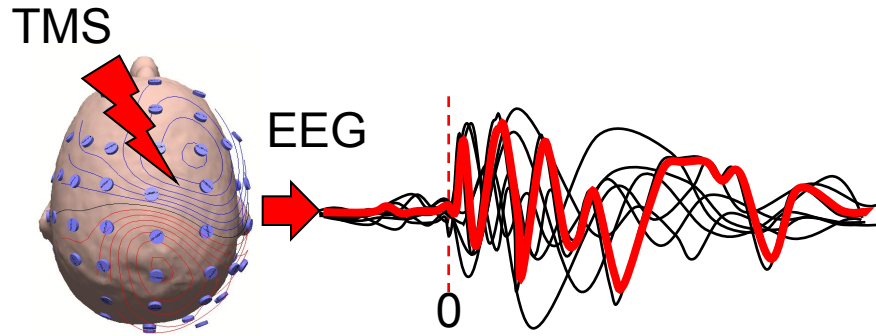




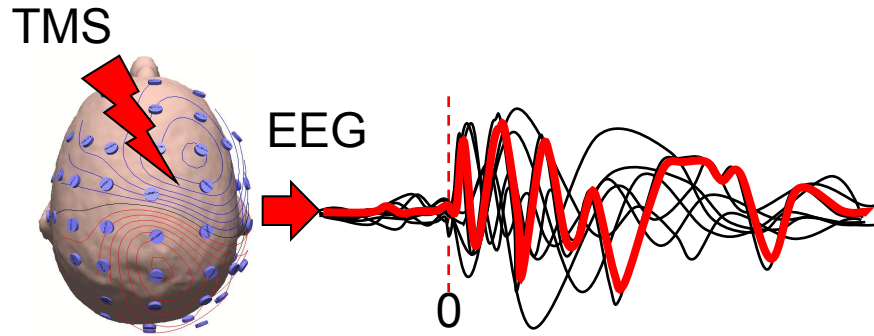




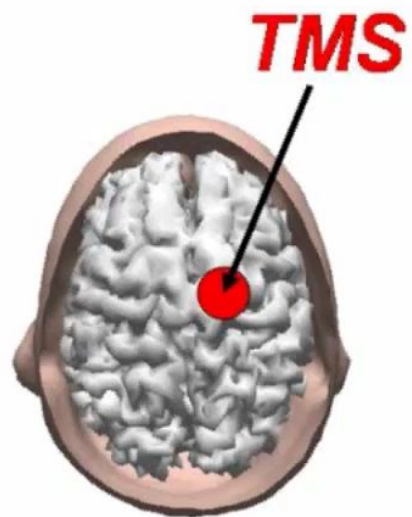
Wakefulness



Wakefulness

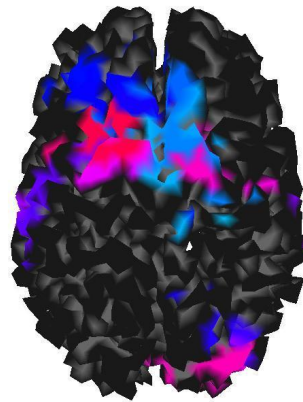
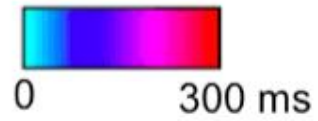
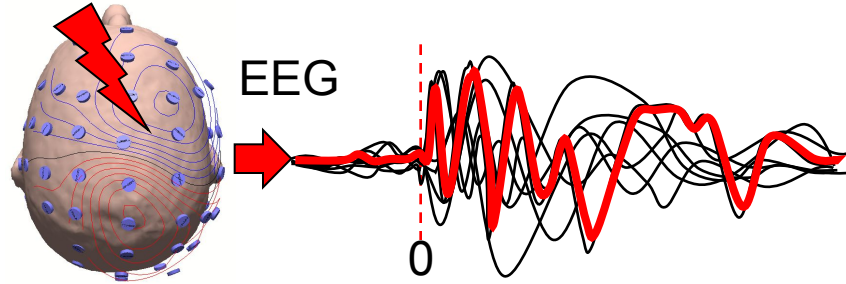


0 ms

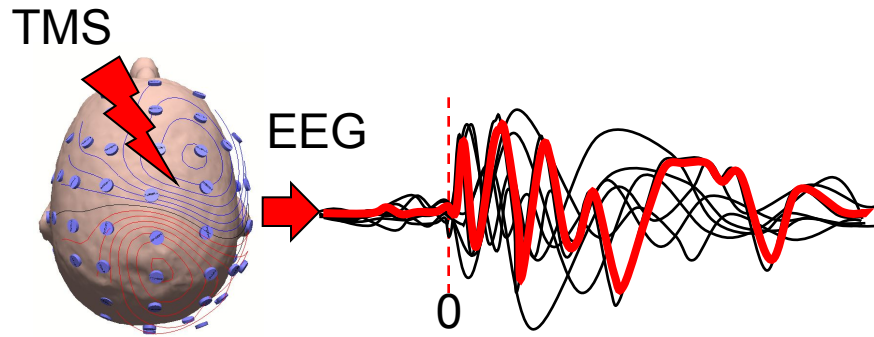


Wakefulness

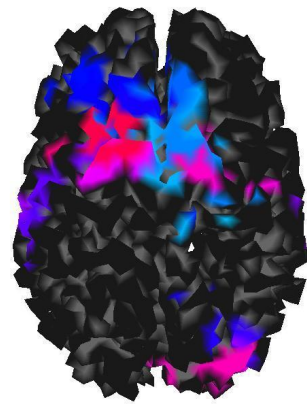
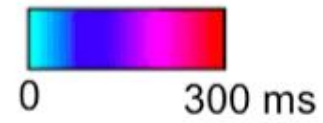
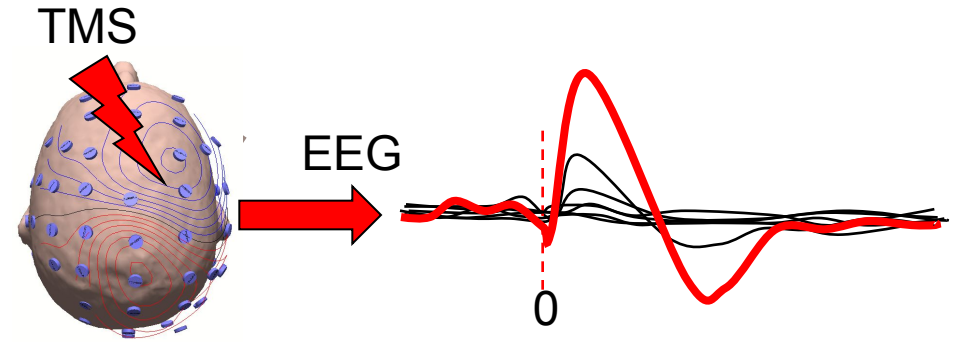
TMS



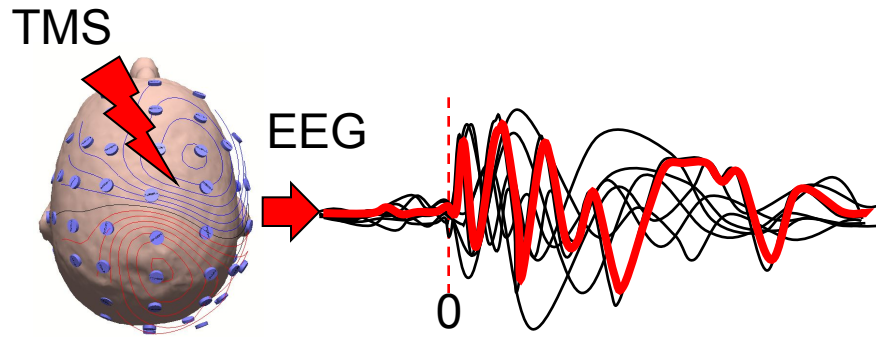
Wakefulness



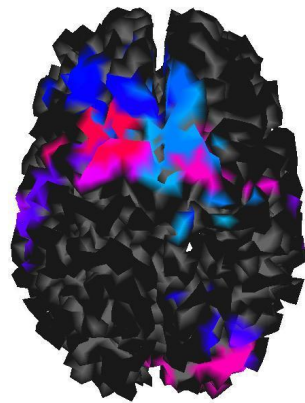
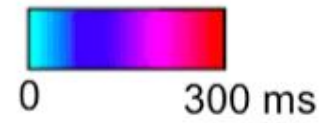
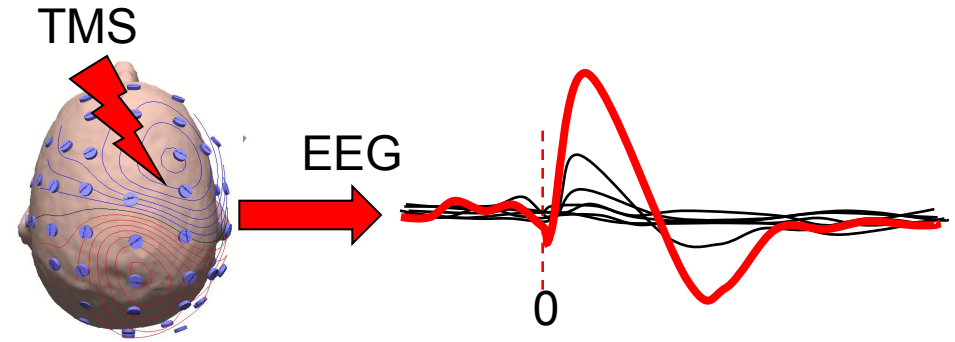
Sleep



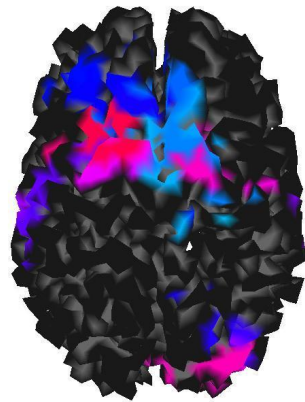
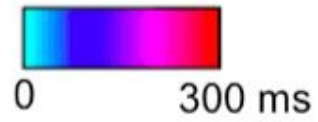
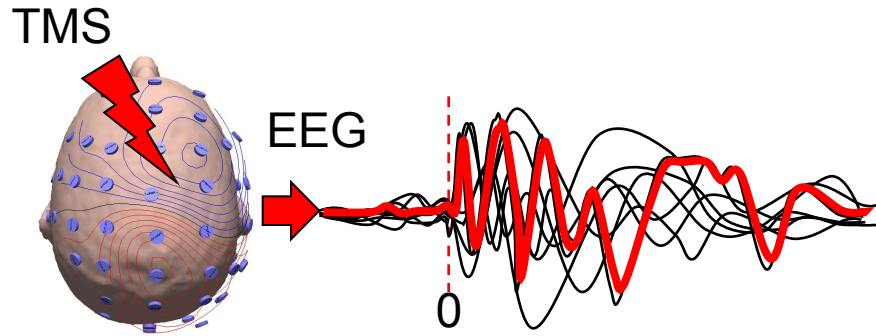
Wakefulness



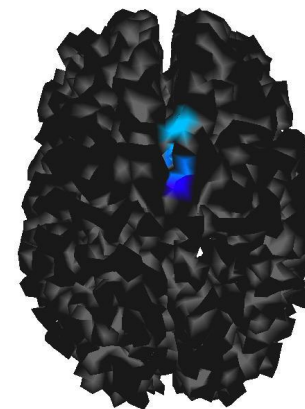
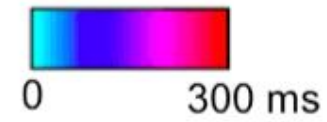
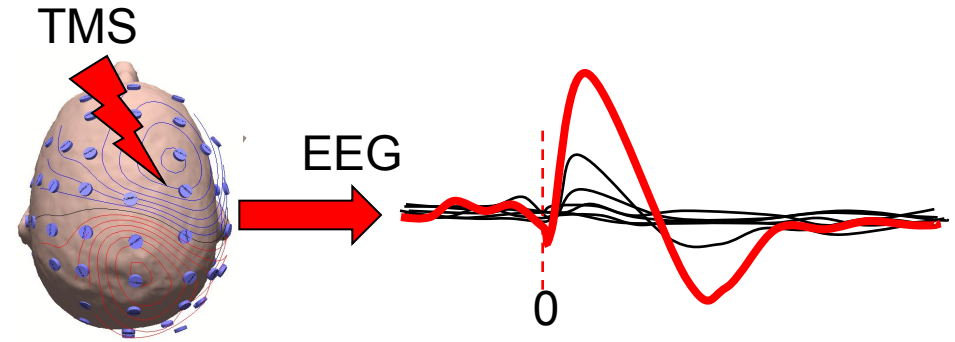
Sleep



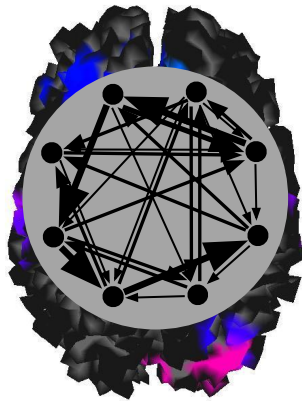
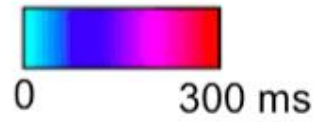
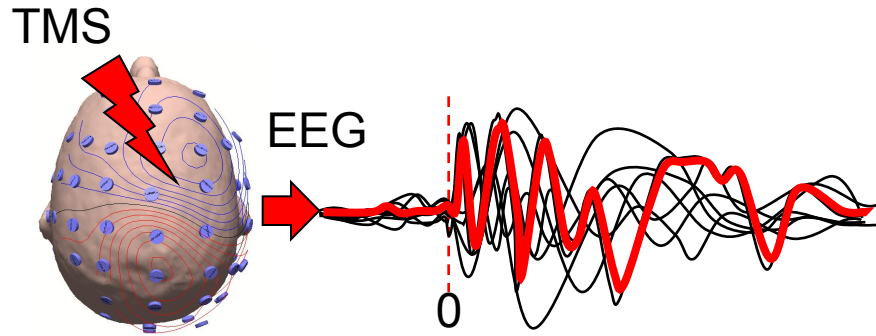
Wakefulness



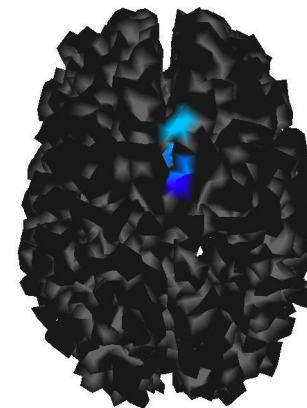
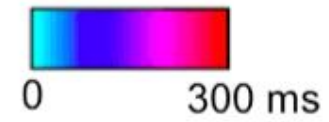
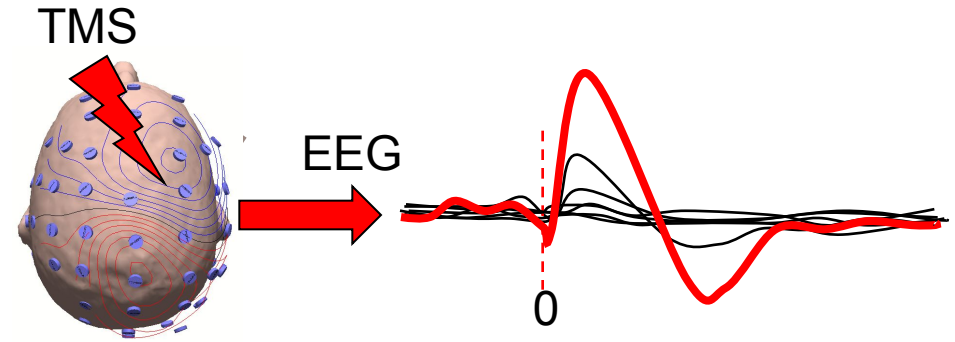
Sleep



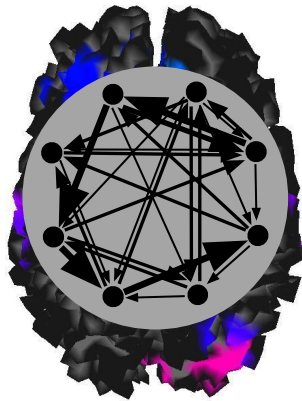
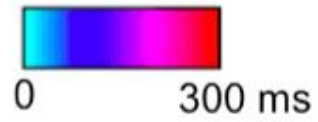
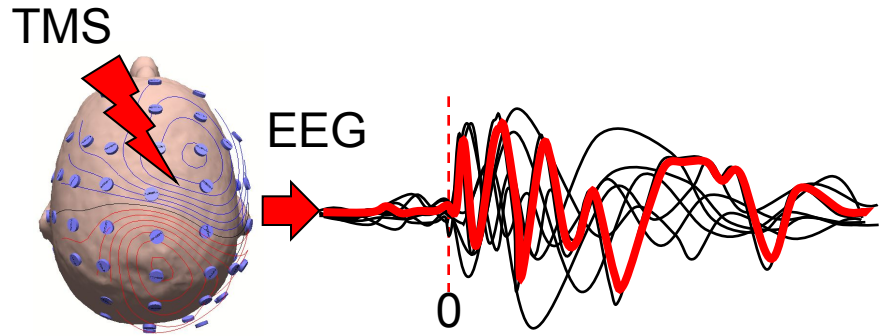
Wakefulness



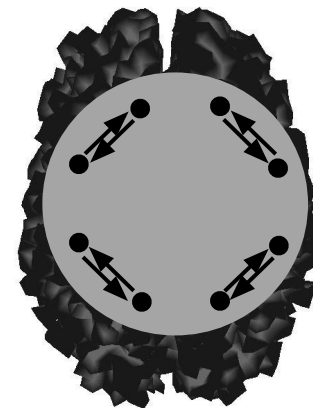
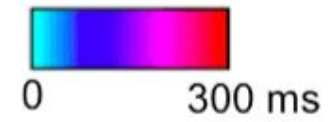
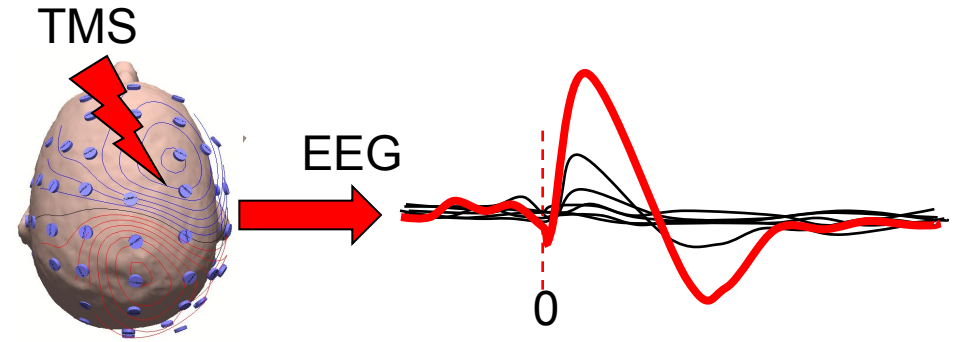
Sleep



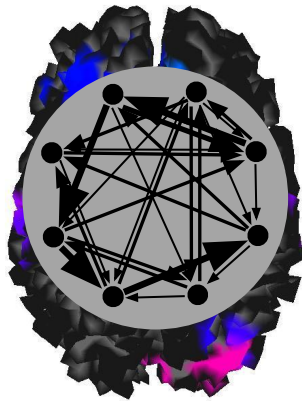
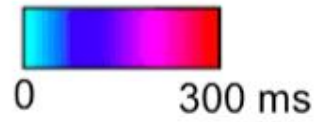
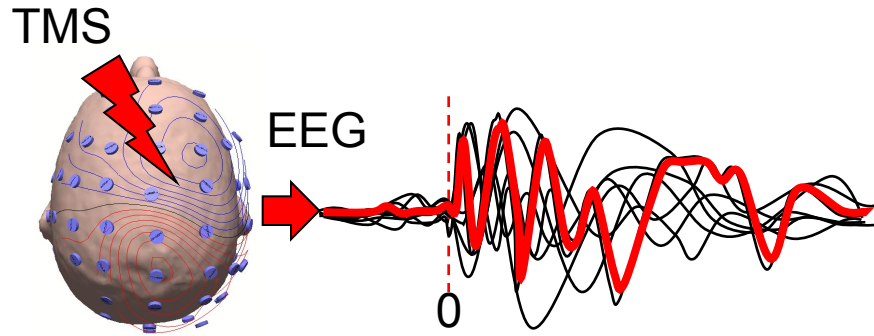
Wakefulness



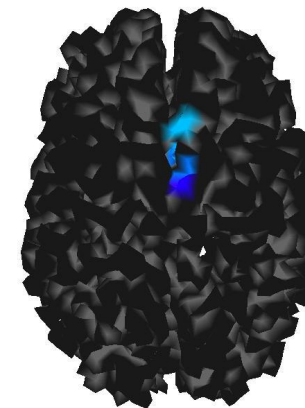
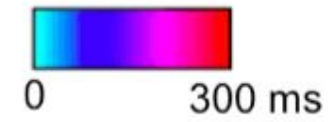
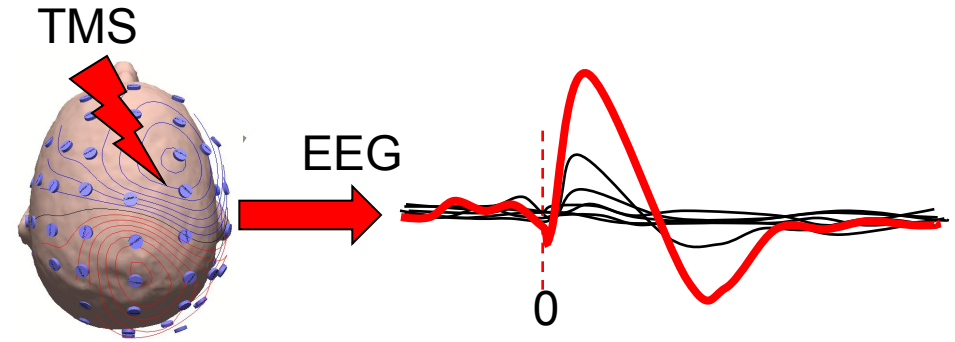
Sleep



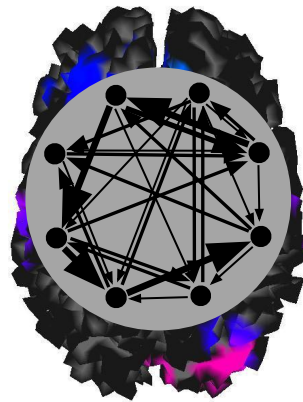
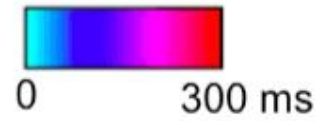
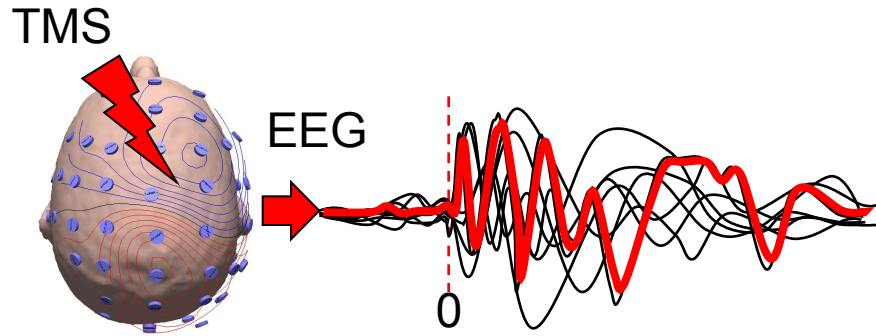
Wakefulness



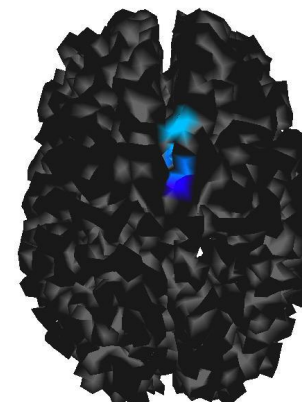
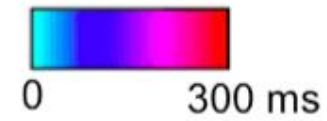
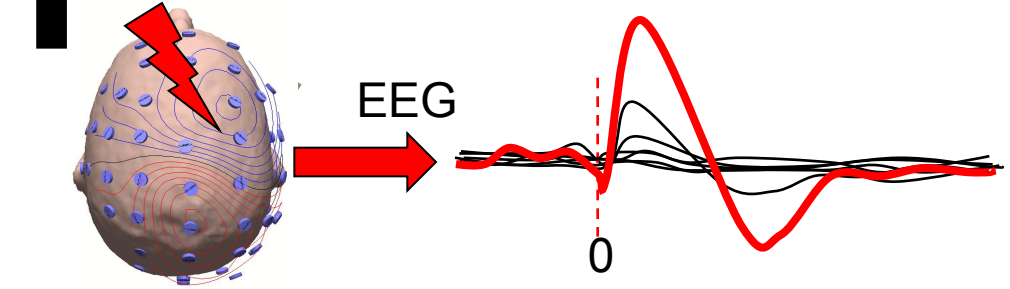
Sleep



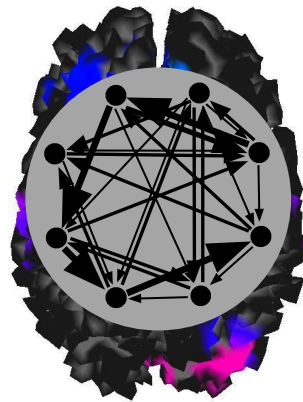
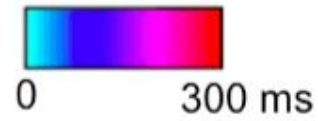
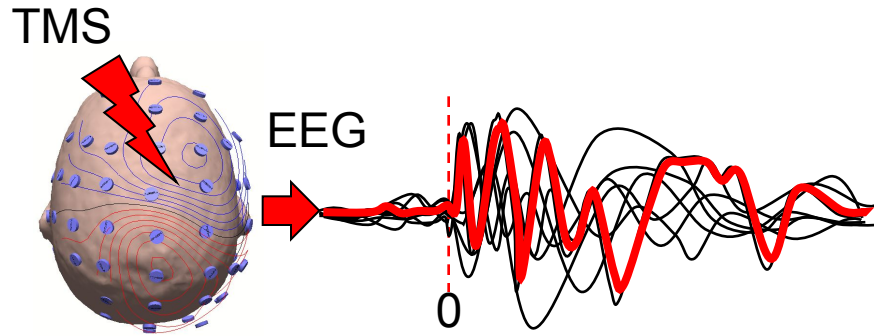
Wakefulness



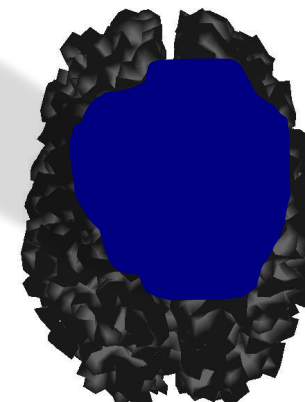
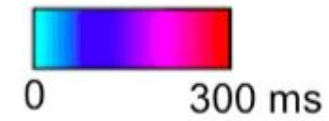
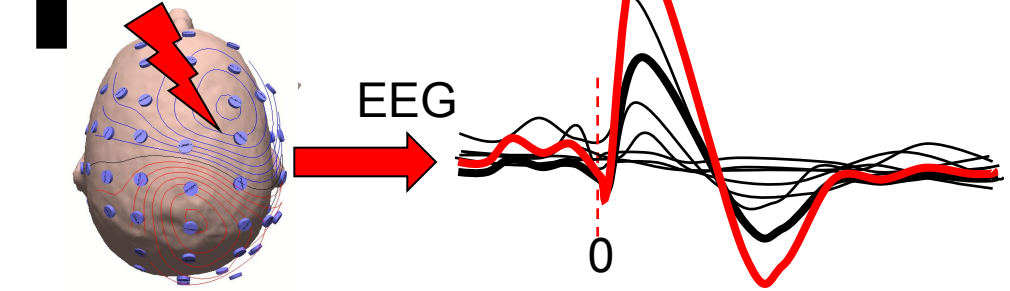
Sleep



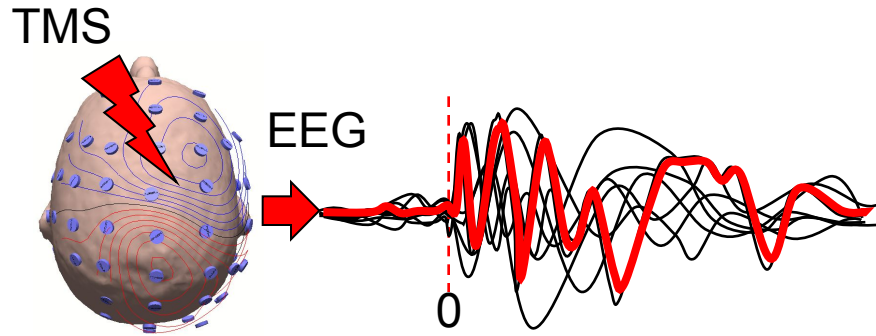
Wakefulness



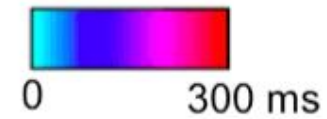
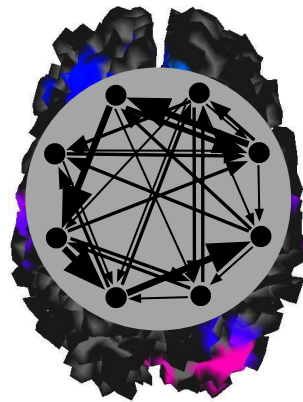
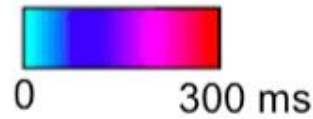
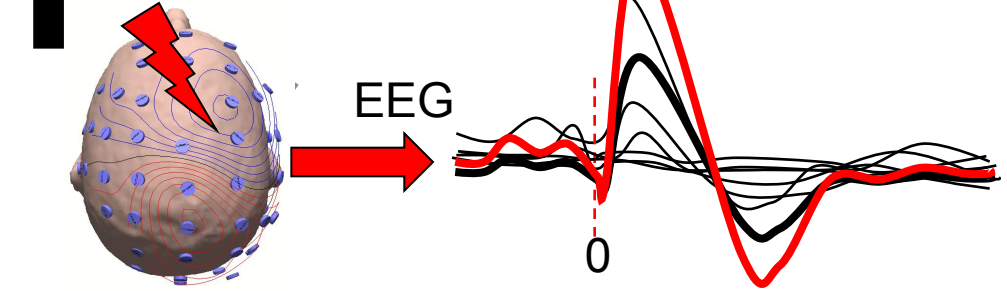
Sleep

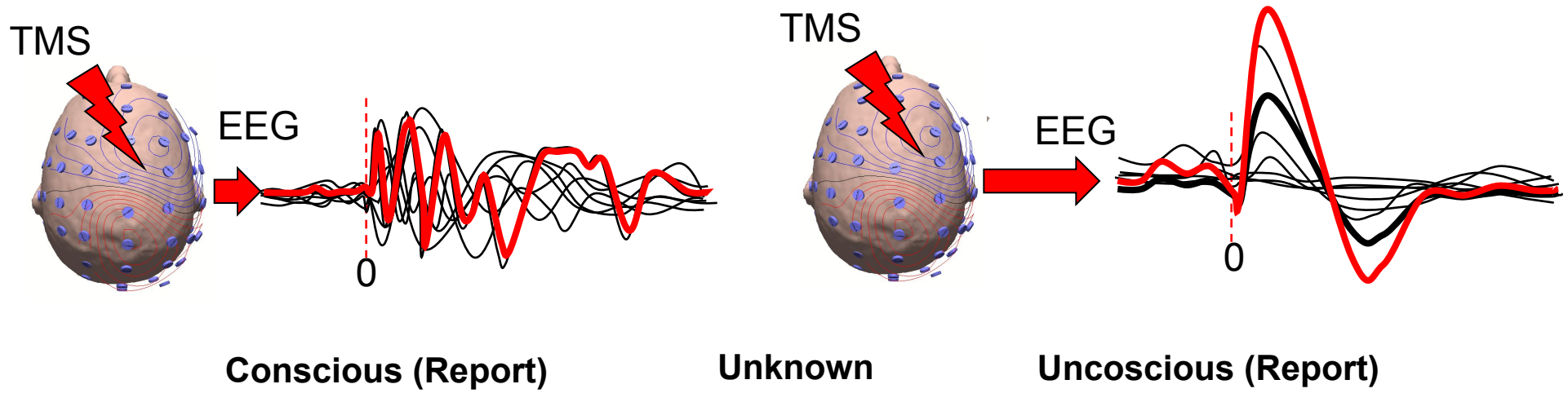


Wakefulness



Sleep

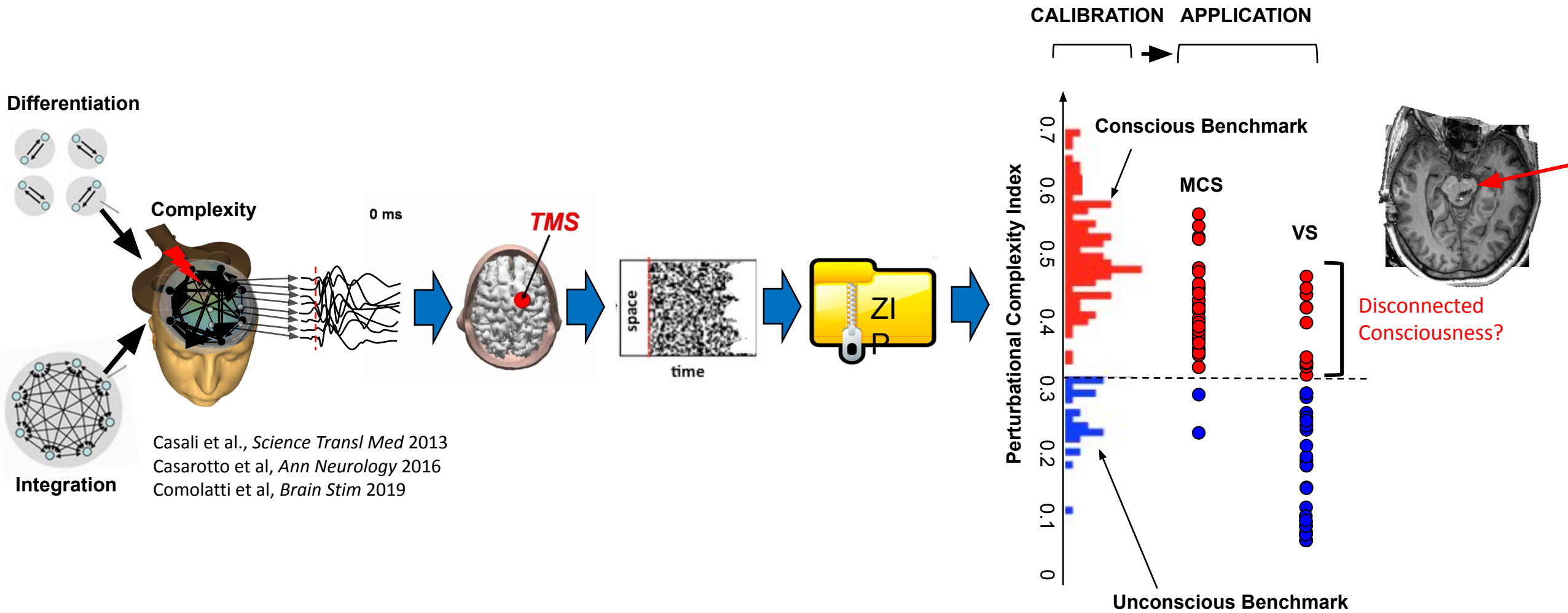




Rosanova et al., *J Neurosci* 2009; Ferrarelli et al., *PNAS* 2010; Rosanova et al., *Brain*, 2012; Casali et al., *Science Transl Med* 2013; Sarasso et al., *Current Biology* 2015;

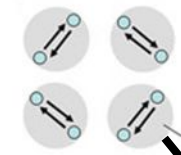


Bedside application: detecting Consciousness through Complexity

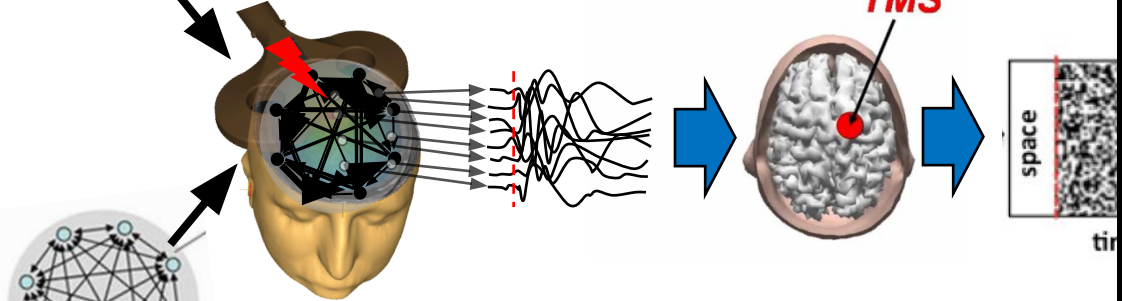


Bedside application: detecting Consciousness through Complexity

Differentiation

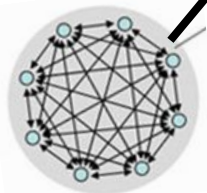


Complexity

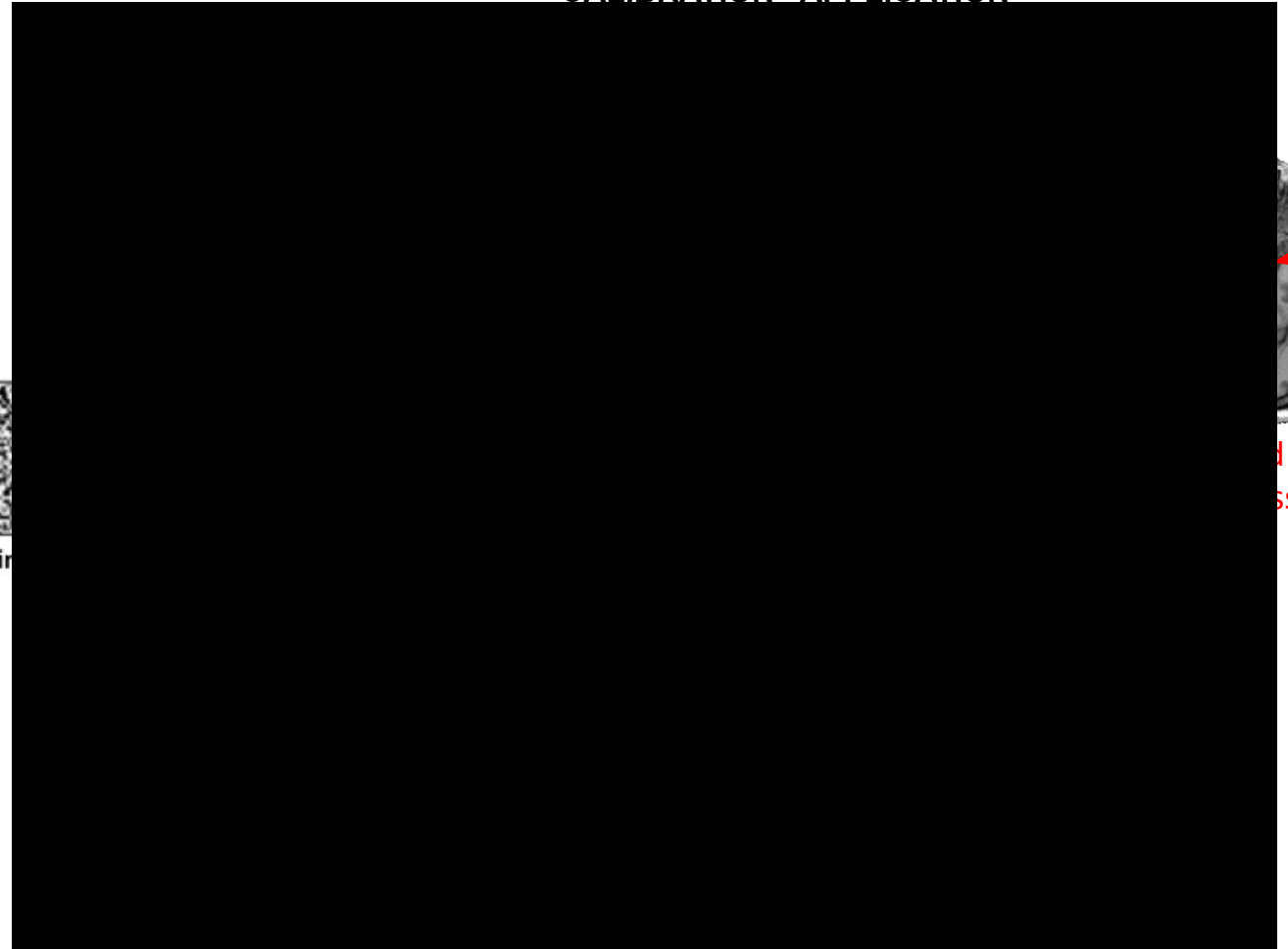


Casali et al., *Science Transl Med* 2013
Casarotto et al, *Ann Neurology* 2016
Comolatti et al, *Brain Stim* 2019

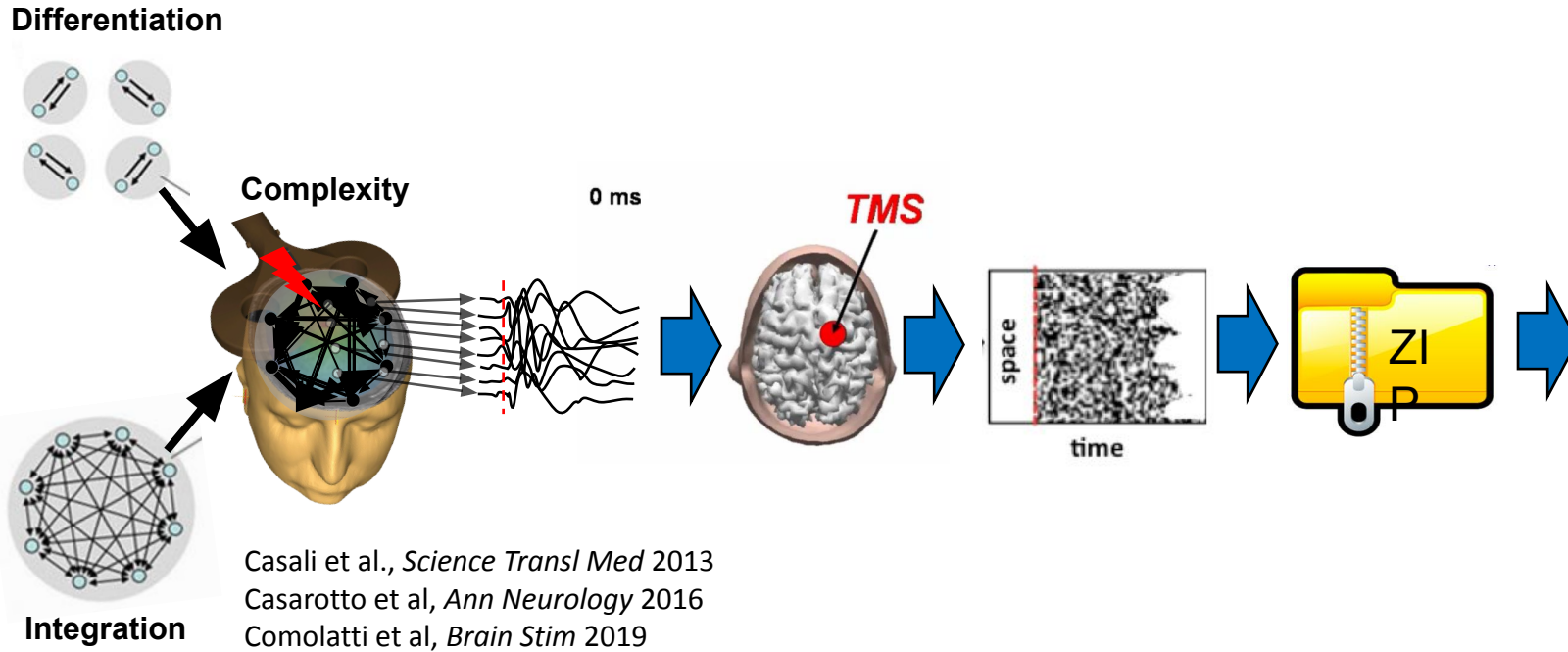
Integration



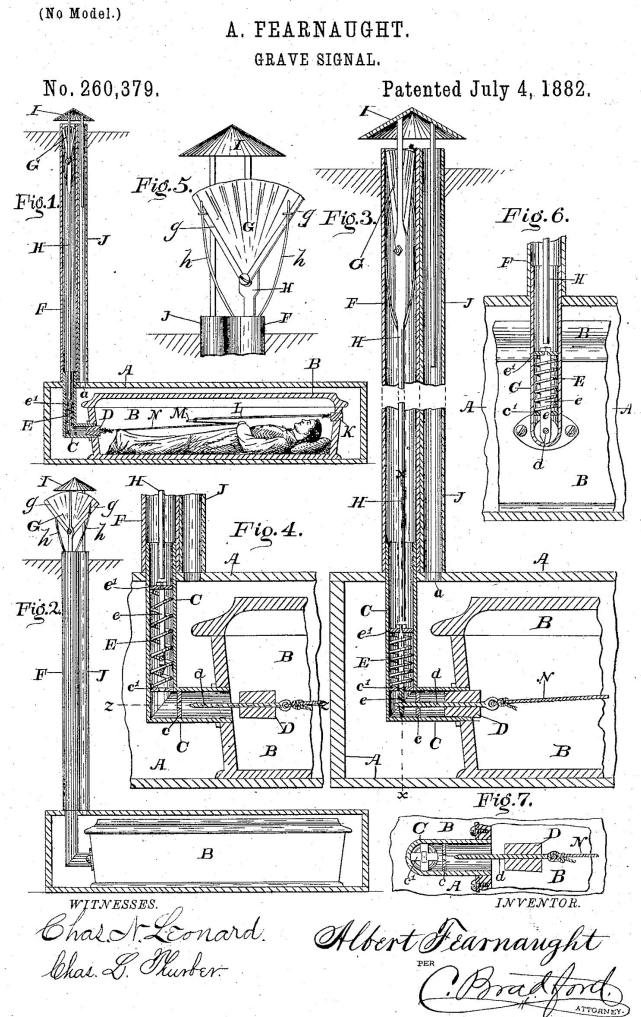
CALIBRATION APPLICATION



Bedside application: detecting Consciousness through Complexity



Safety Coffin



Bedside application: detecting Consciousness through Complexity

Information Sharing in the Brain Indexes Consciousness in Noncommunicative Patients

Jean-Ré
Frédéric
Laurent
and Sta

Global and local complexity of intracranial EEG decreases during NREM sleep

Michael M. Schartner
Anil K. Seth^{1,†} and A

SCIENCE ADVANCES | RESEARCH ARTICLE

COGNITIVE NEUROSCIENCE

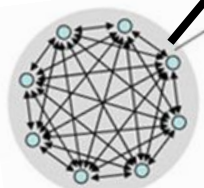
Human consciousness is supported by dynamic complex patterns of brain signal coordination

A. Demertzi^{1,2,3,*†}, E.
F. Raimondo^{1,2,3,10,11},
H. U. Voss¹⁷, N. D. Sc

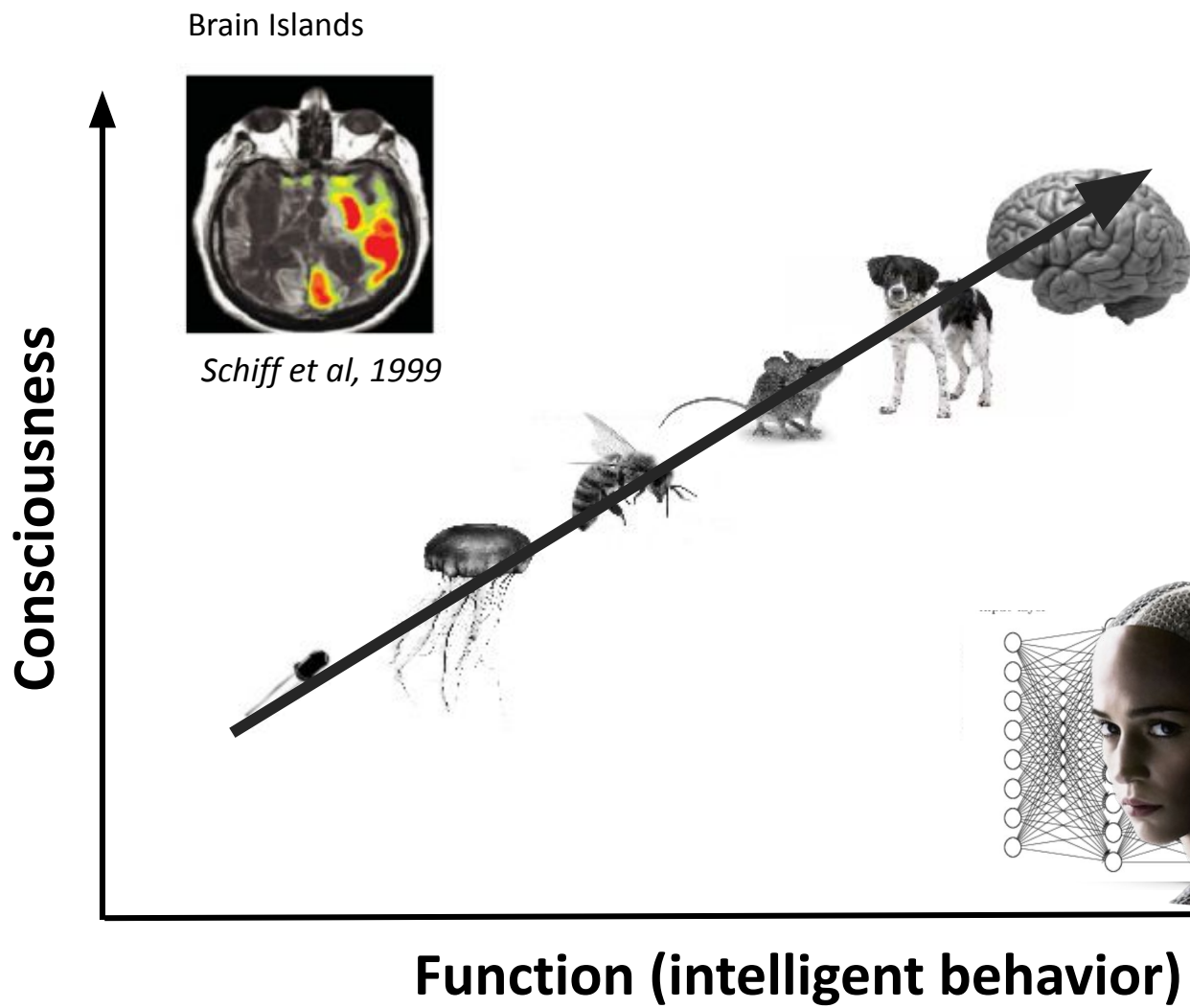
Decreased integration of EEG source-space networks in disorders of
consciousness

Jennifer Rizkallah^{a,b}, Jitka Annen^{c,d}, Julien Modolo^{a,*}, Olivia Gosseries^{c,d}, Pascal Benquet^a,
Sepehr Mortaheb^c, Hassan Amoud^b, Helena Cassol^{c,d}, Ahmad Mheich^a, Aurore Thibaut^{c,d},
Camille Chatelle^{c,d}, Mahmoud Hassan^a, Rajanikant Panda^c, Fabrice Wendling^{a,1},
Steven Laureys^{c,d,1}

Casali et al., *Science Transl Med*
Casarotto et al, *Ann Neurology*
Comolatti et al, *Brain Stim* 2019

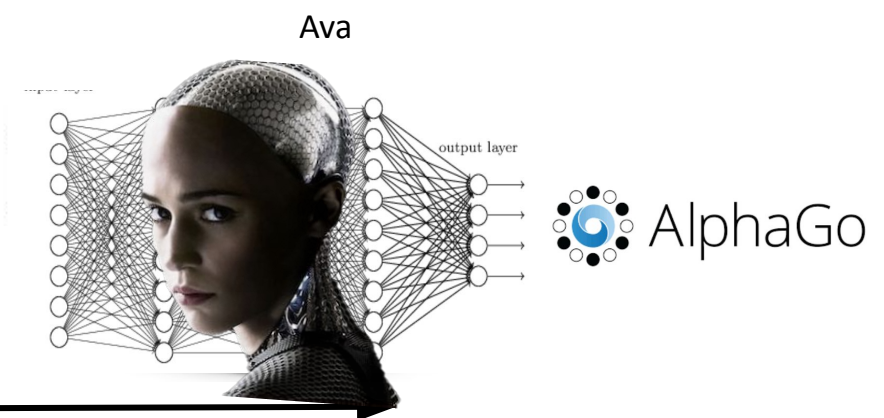


Integration



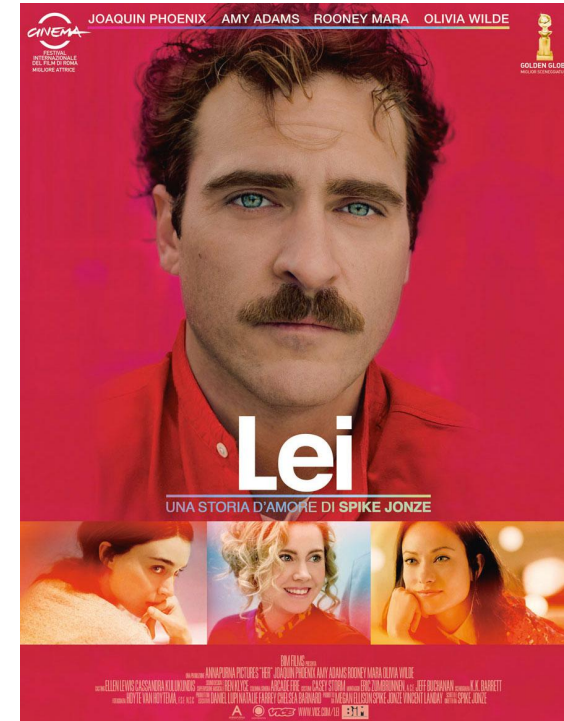
World's best Go player flummoxed by Google's 'godlike' AlphaGo AI

Ke Jie, who once boasted he would never be beaten by a computer at the ancient Chinese game, said he had 'horrible experience'



Patient

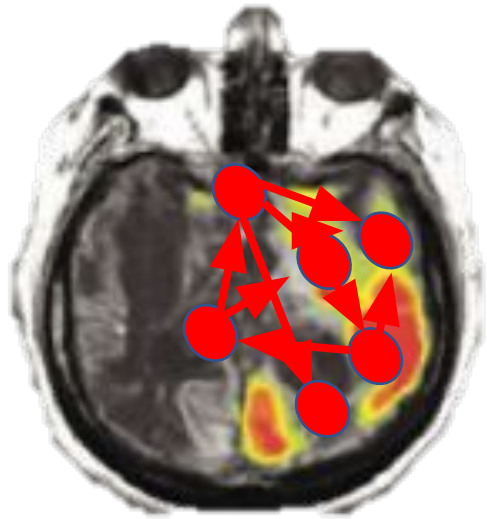
Sofia



With the kind patient's family permission



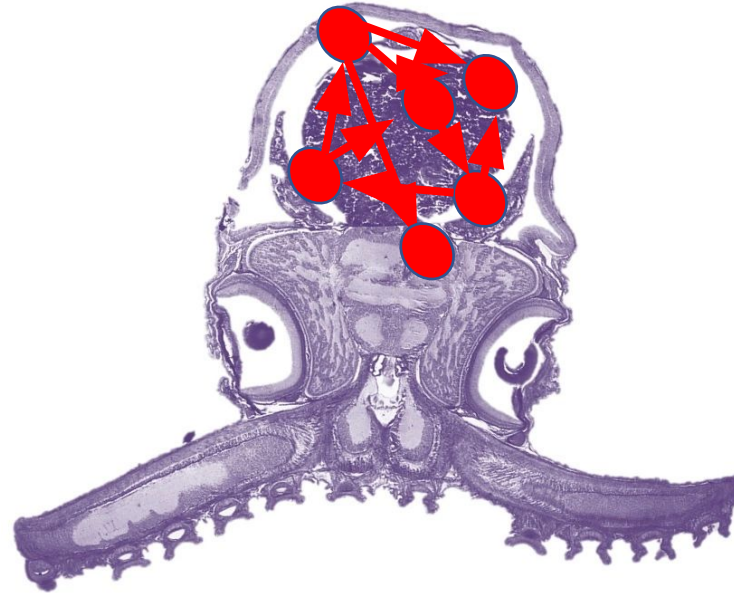
Injured Brains



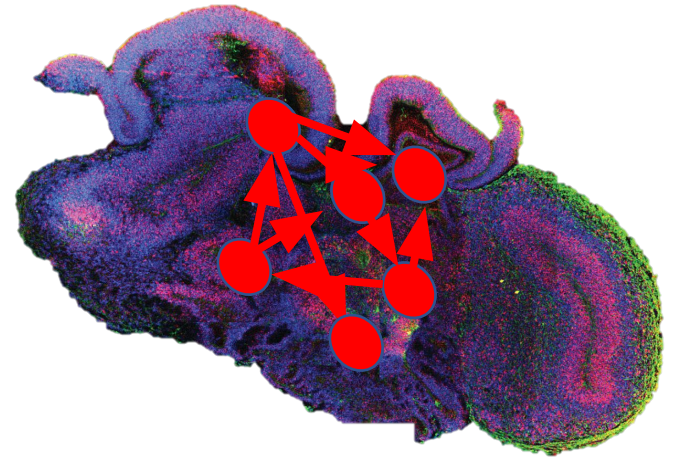
Developing Brains



Other Brains



Brain Islands



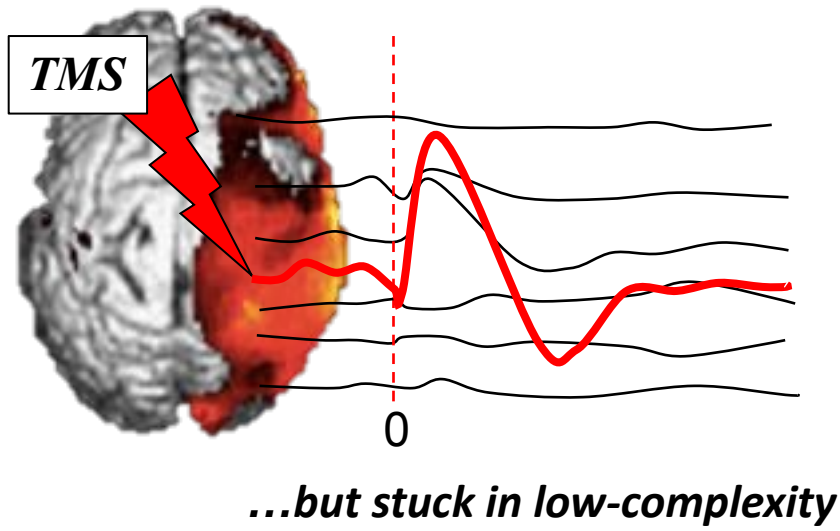
Evaluating Complexity of Fetal MEG Signals: A Comparison of Different Metrics and Their Applicability

Julia Moser^{1*}, Siouar Bensaid², Eleni Kroupi³, Franziska Schleger¹, Fabrice Wendling², Giulio Ruffini³ and Hubert Preißl¹

Edelman, Baars, Seth *Consc Cogn* 2005

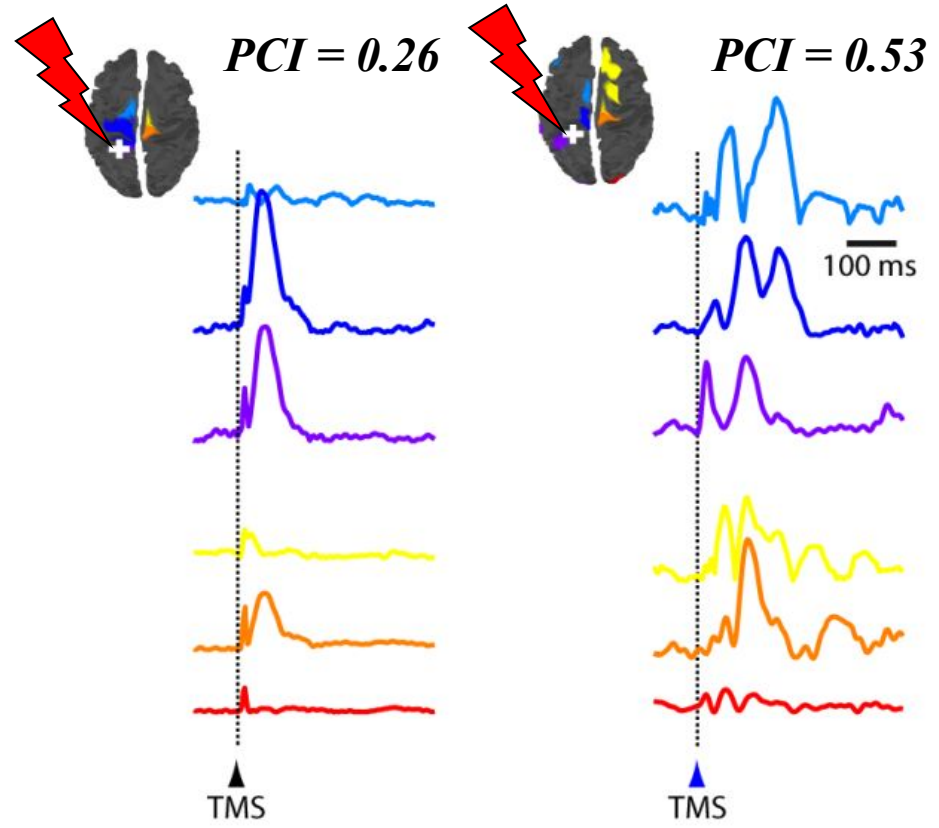
Bayne, Seth, Massimini *TINS*, *in press*

Structurally intact, metabolically active,...



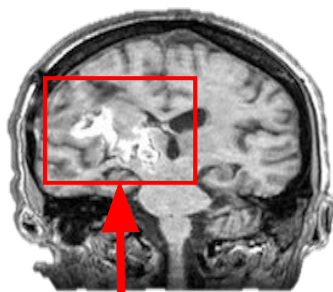
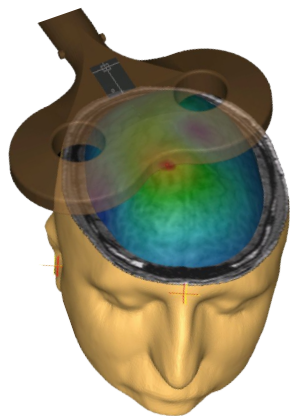
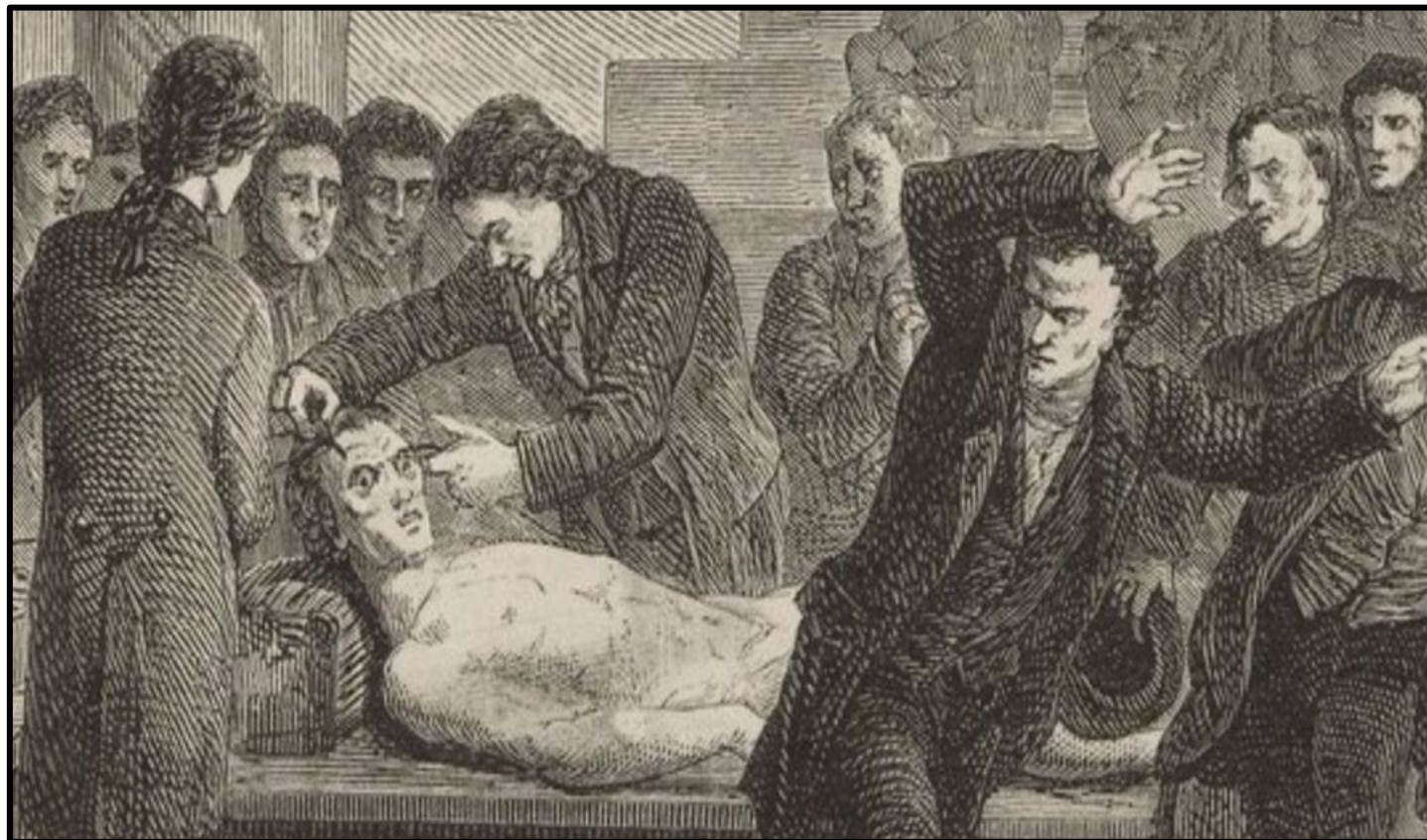
Bodart et al., *Neuroimage Clin* 2018

Vegetative State → *Recovery*

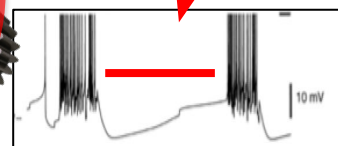
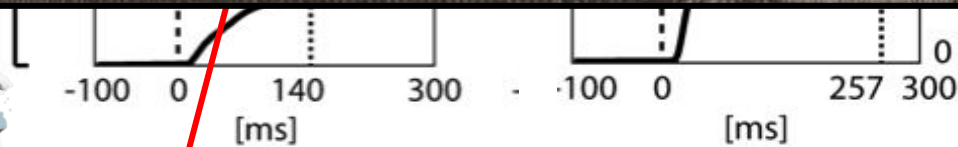


Rosanov et al., *Brain* 2013

Sleep-like cortical OFF-periods disrupt causality and complexity in the brain of unresponsive wakefulness syndrome patients



structural
lesion



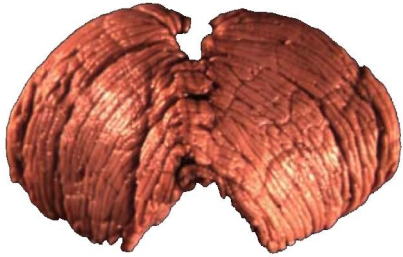
Neuronal OFF-period



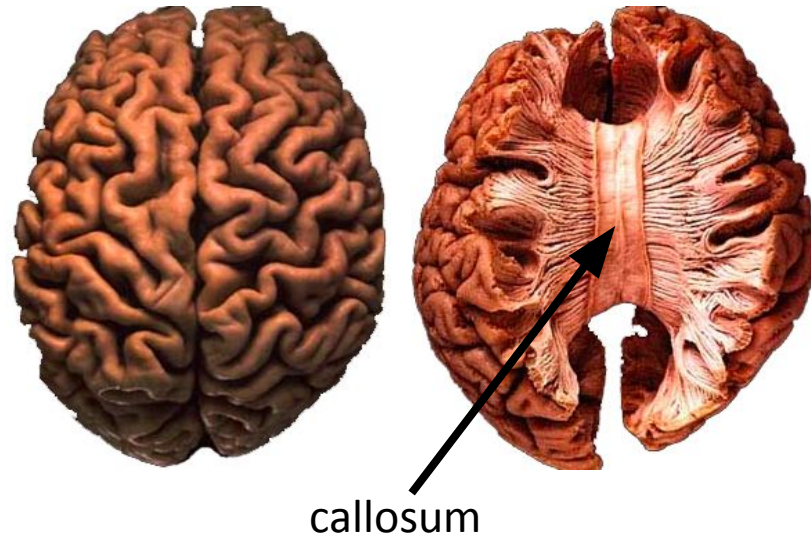
CORTEX



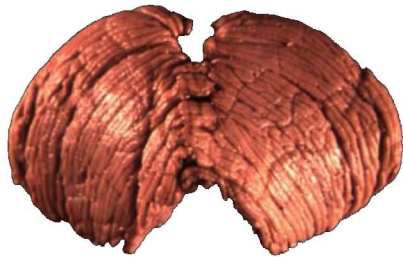
CEREBELLUM



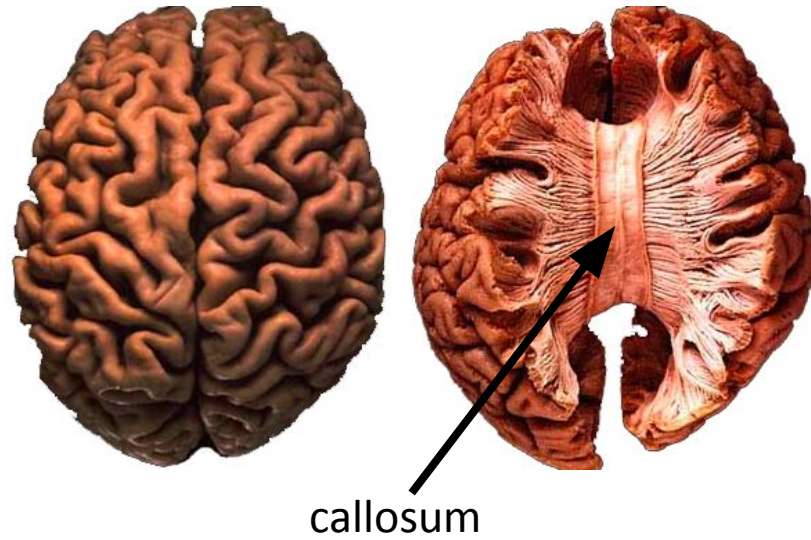
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CEREBELLUM



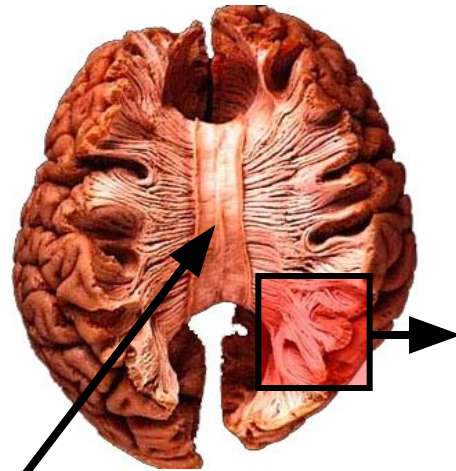
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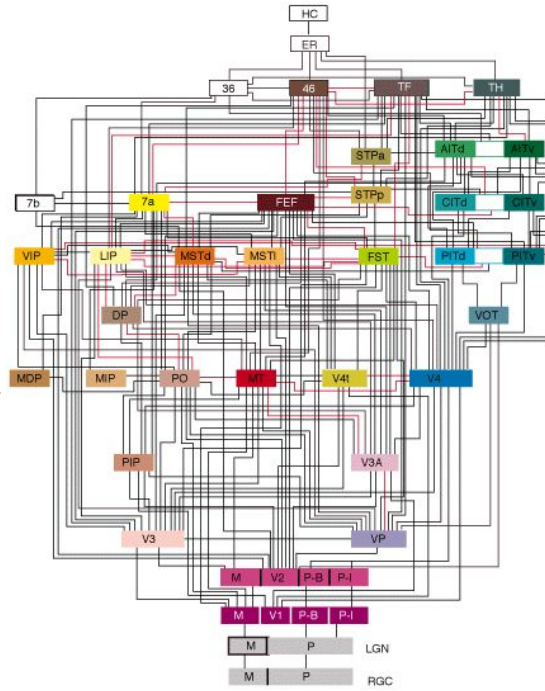
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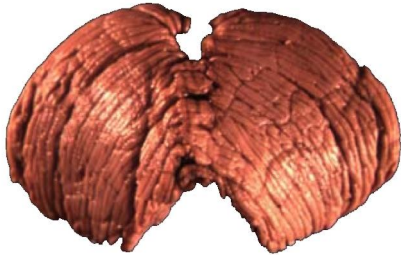
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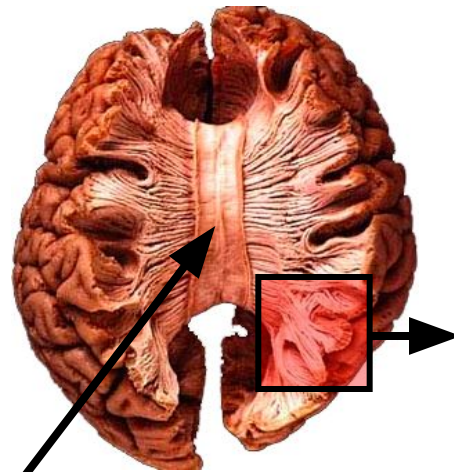
callosum



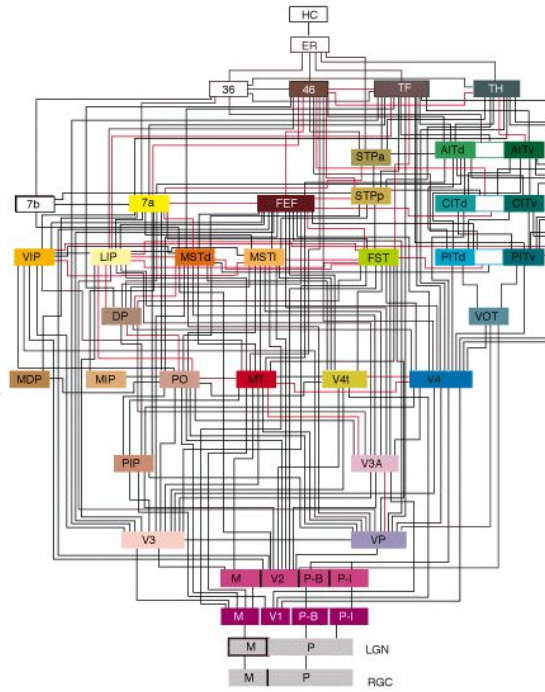
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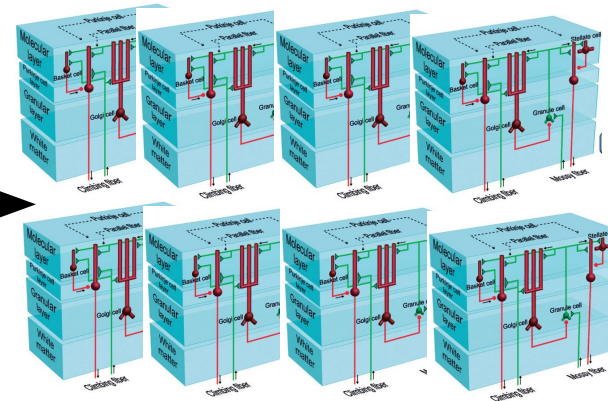
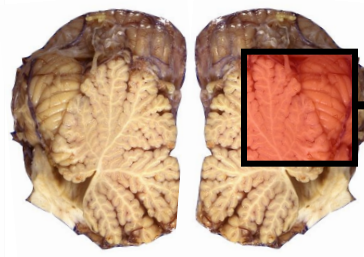
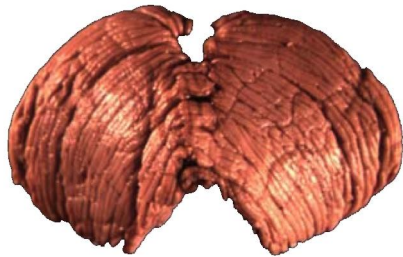
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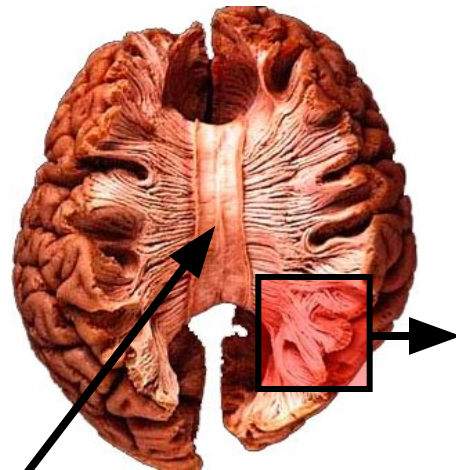
callosum



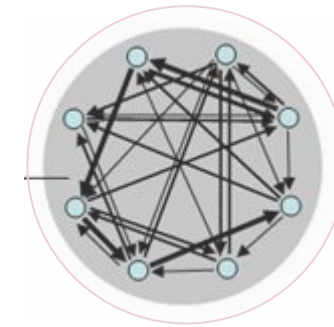
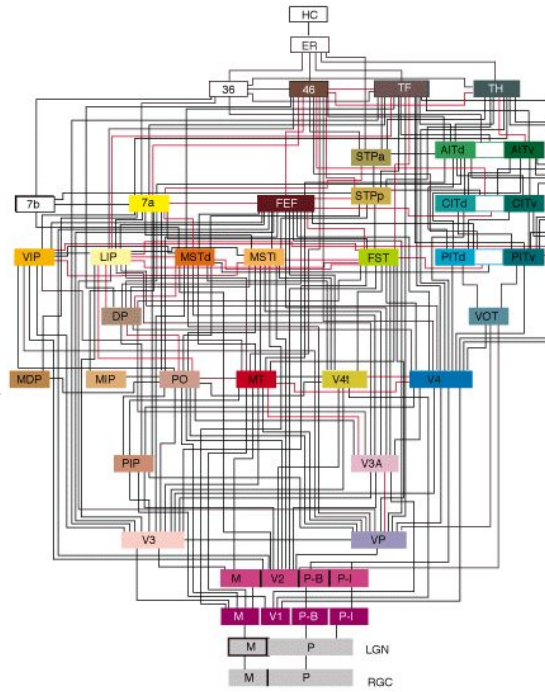
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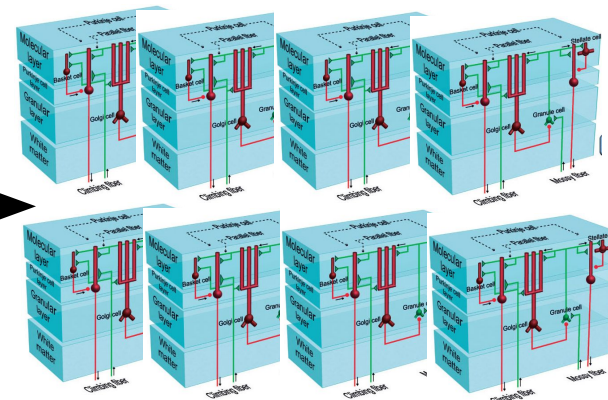
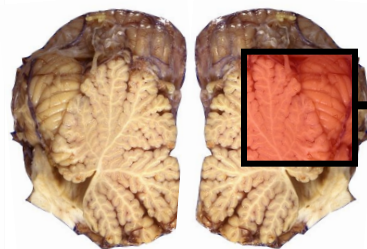
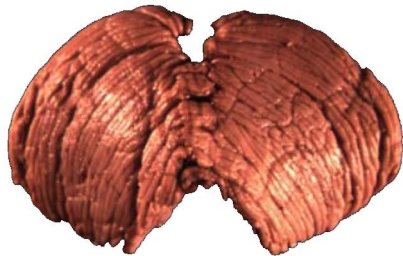
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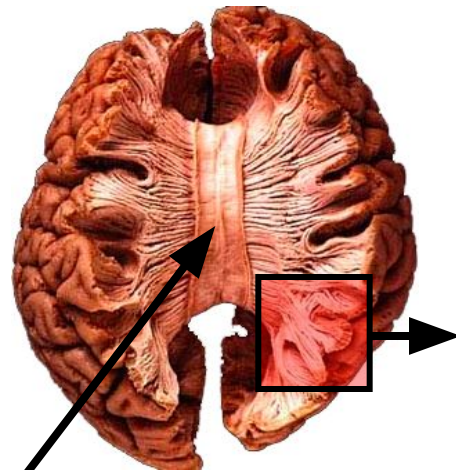
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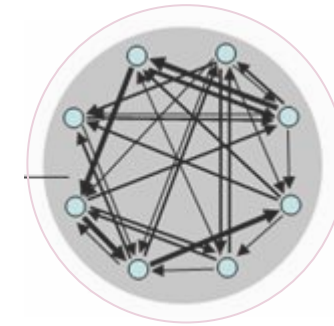
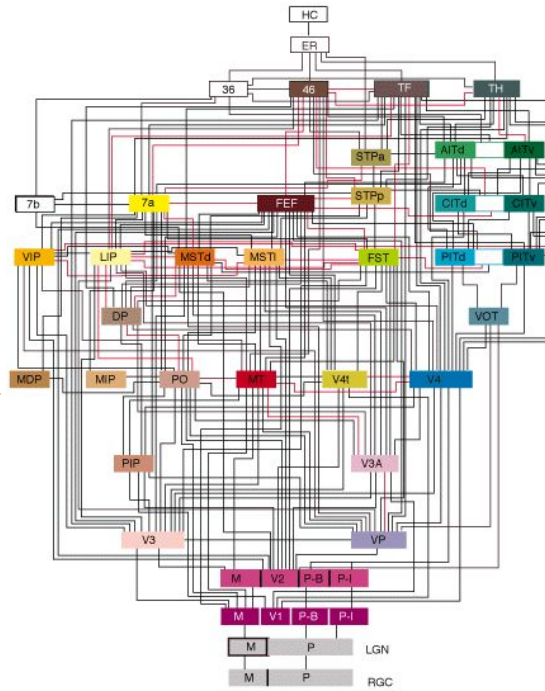
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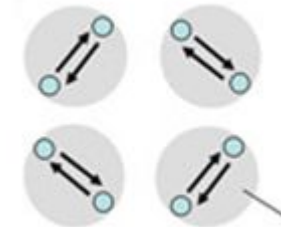
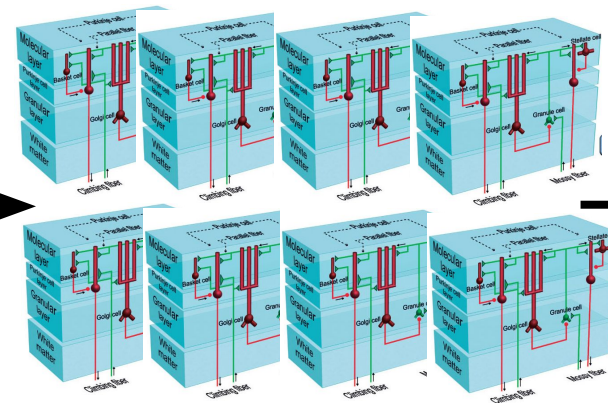
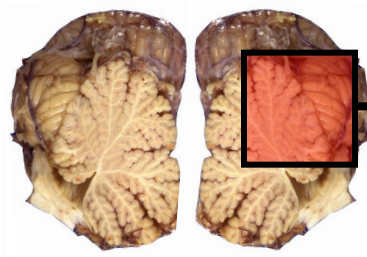
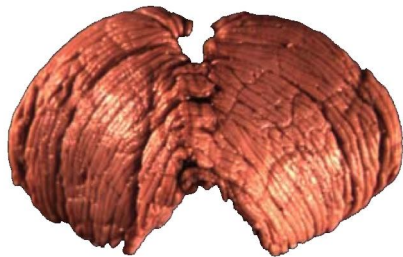
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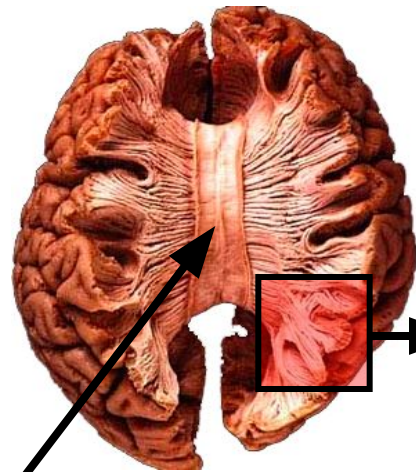
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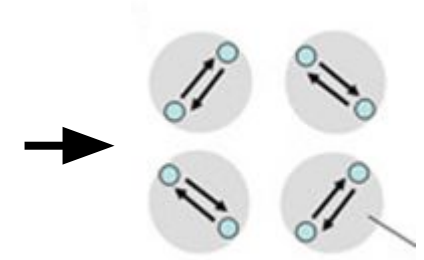
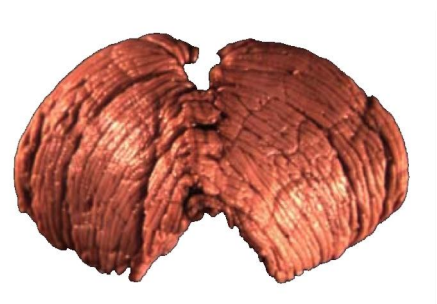
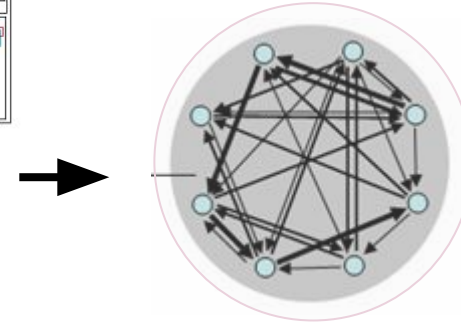
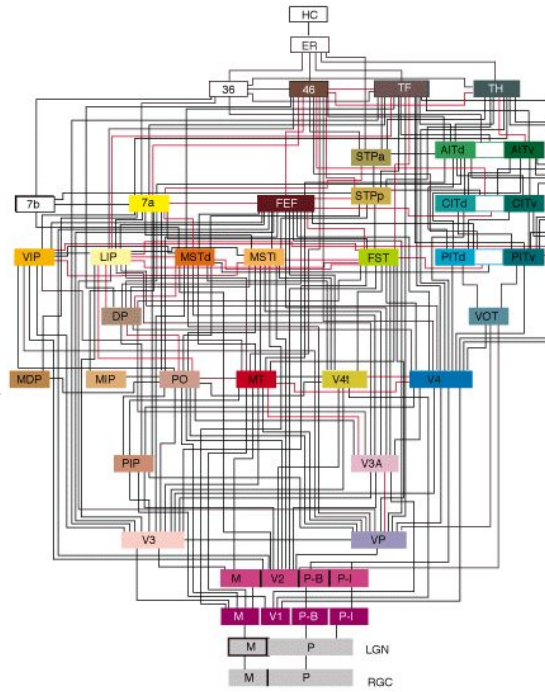
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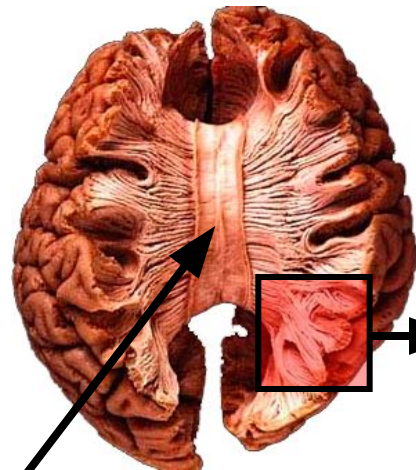
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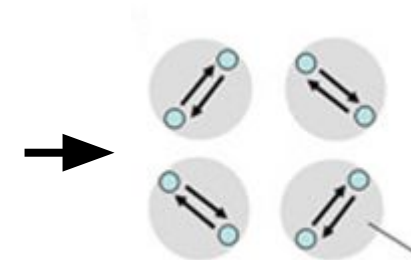
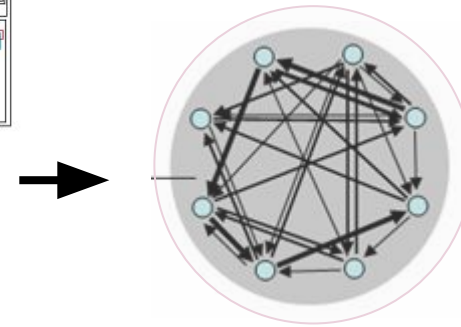
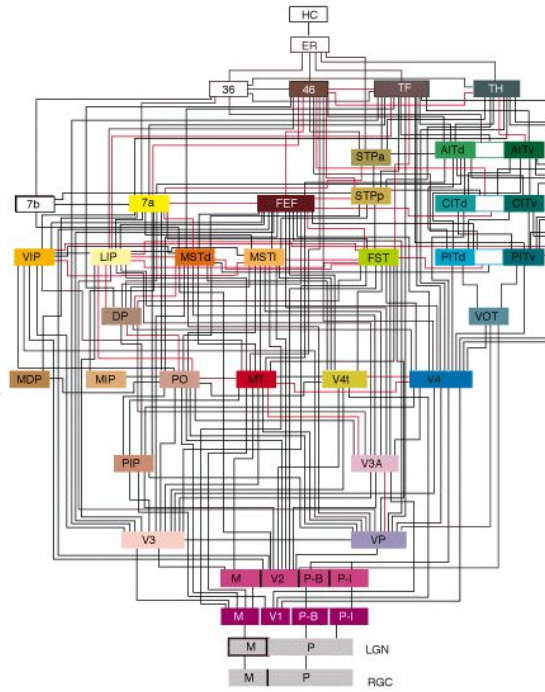
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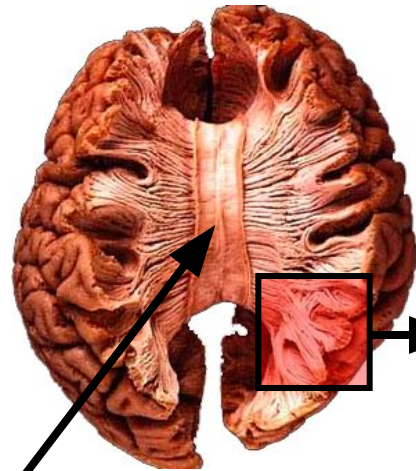
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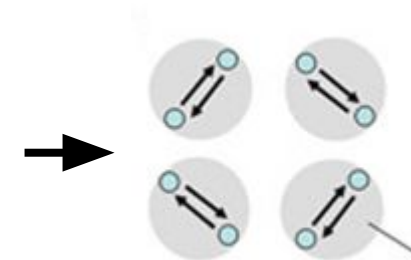
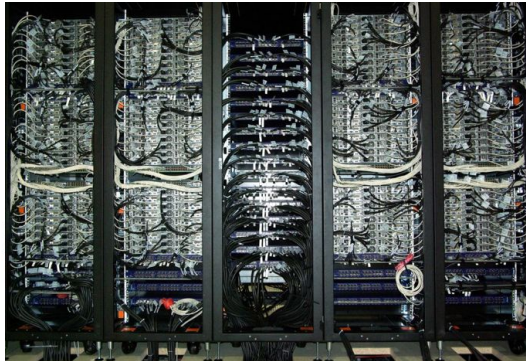
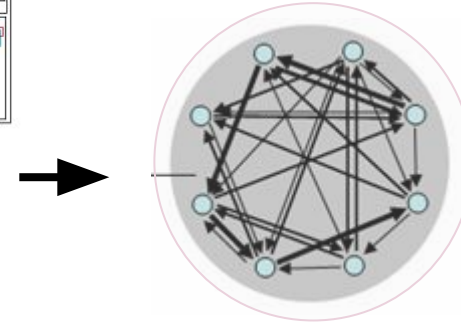
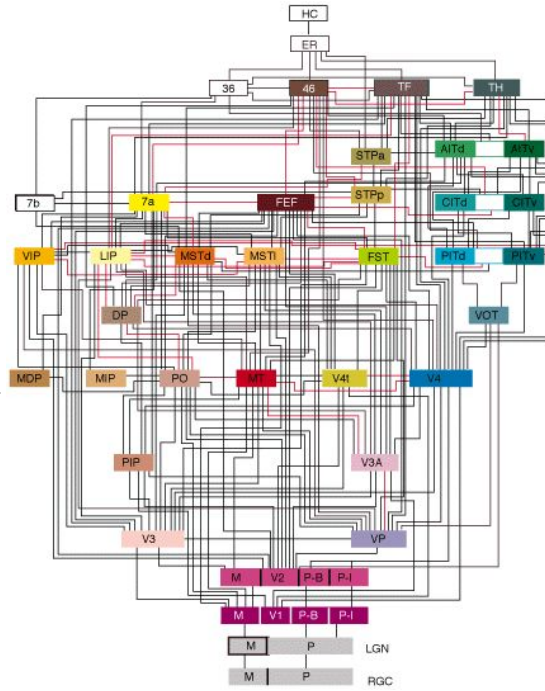
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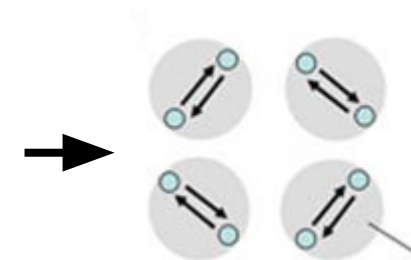
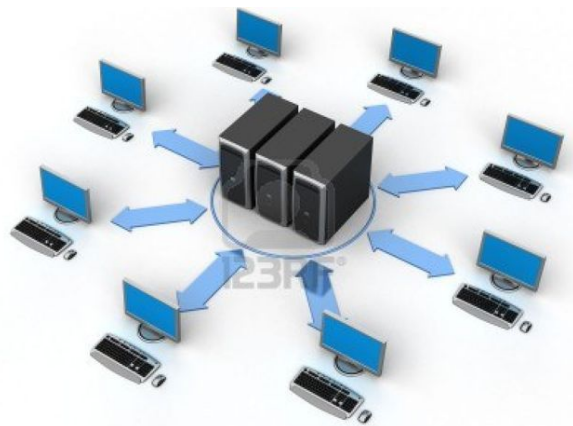
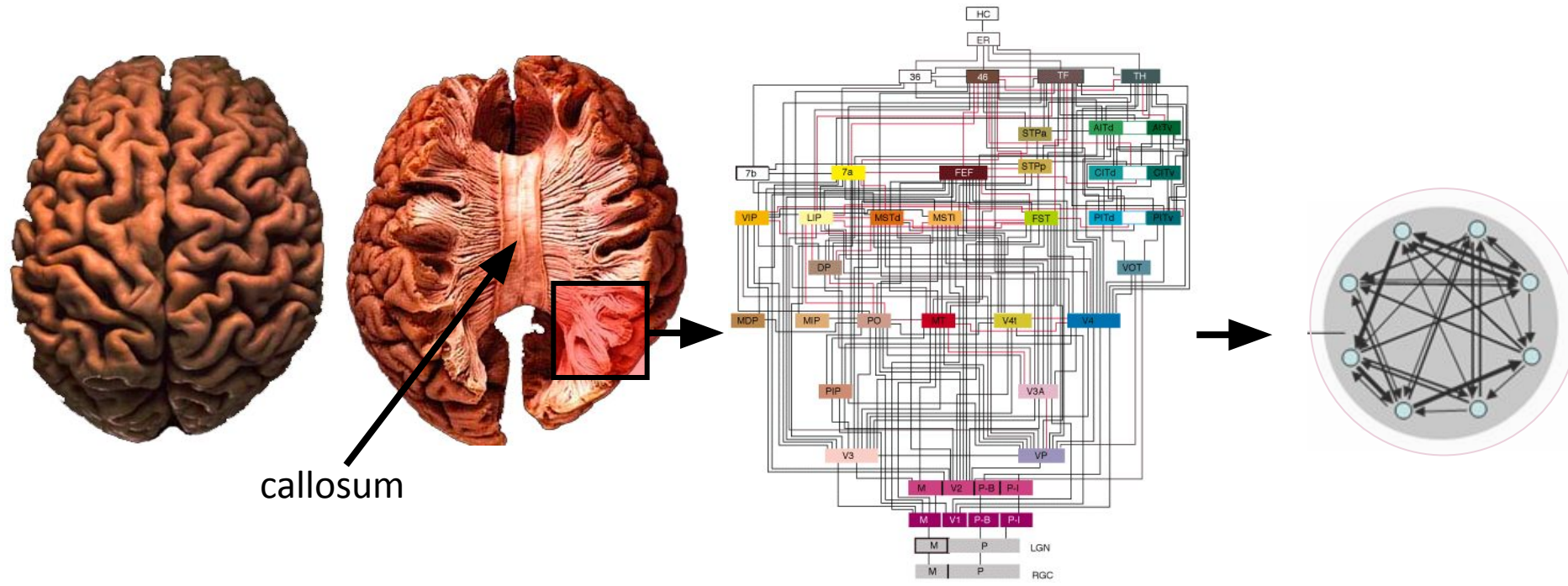
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callosum



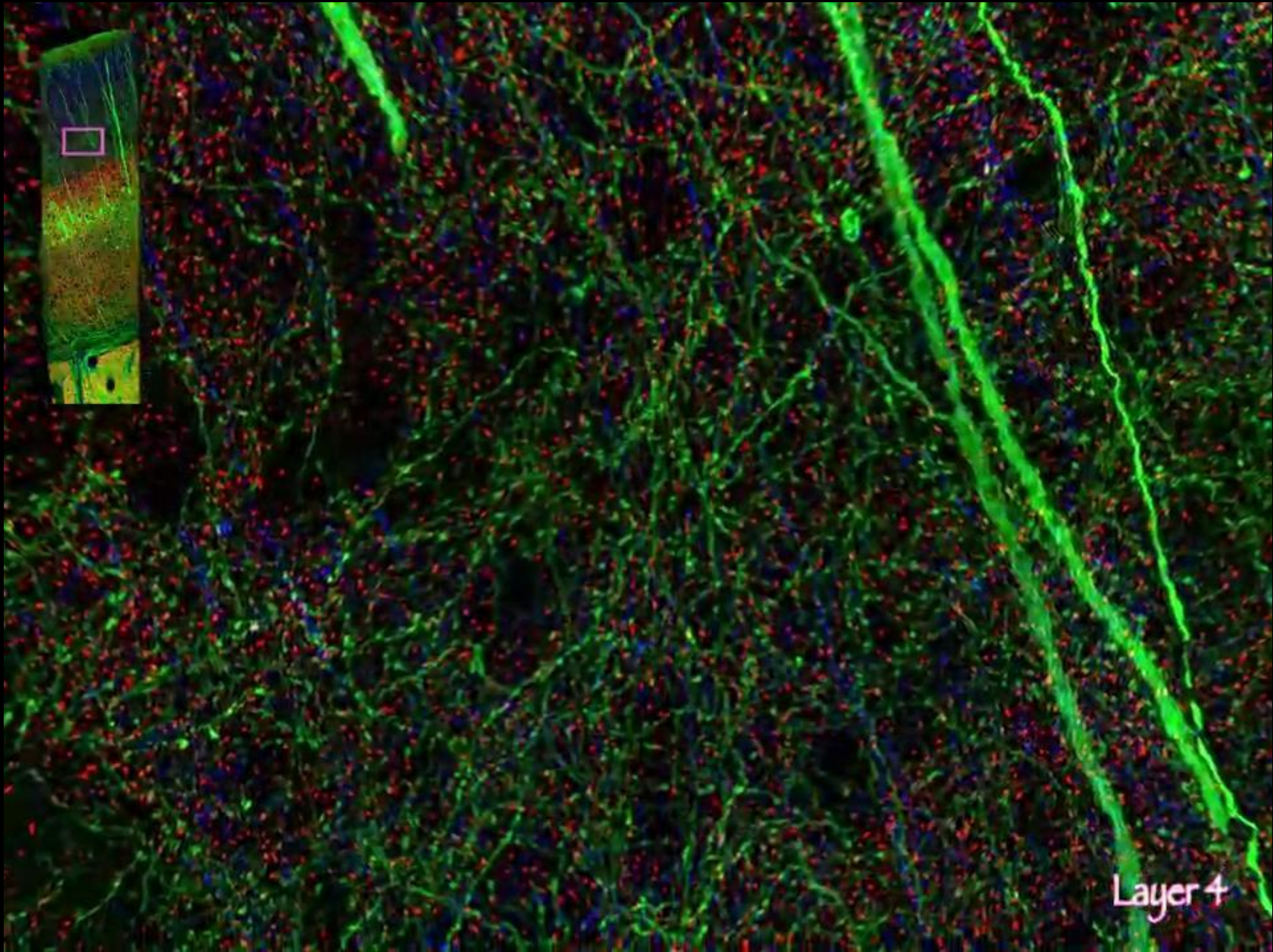
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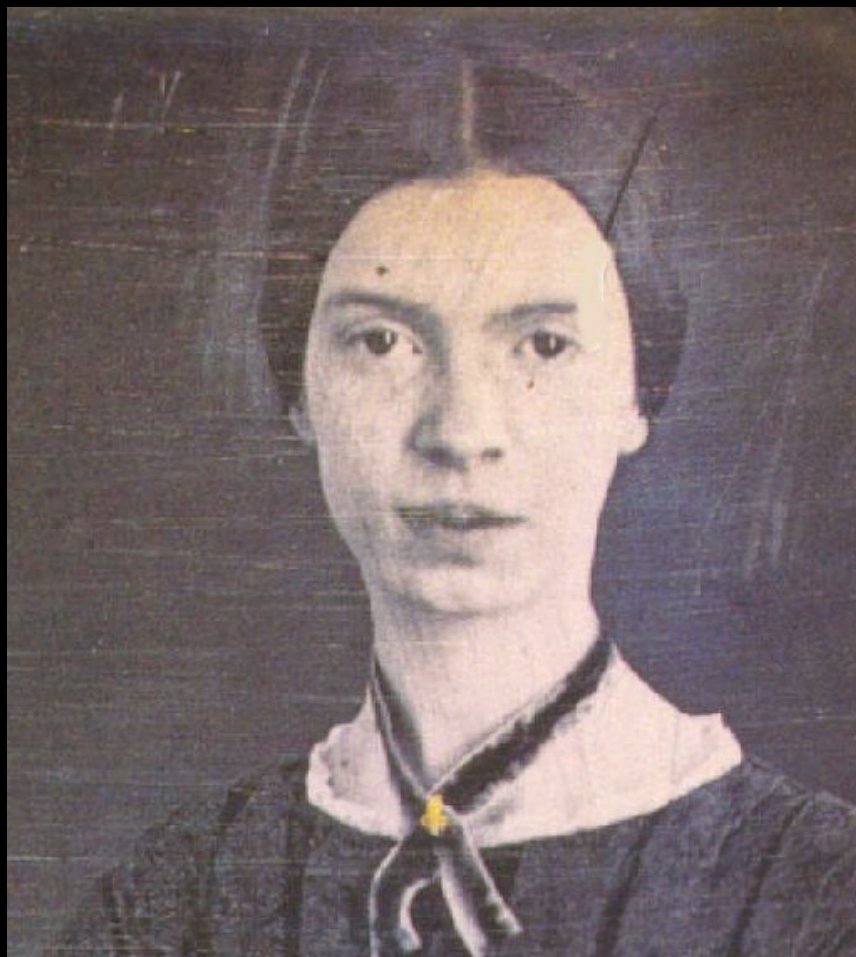
Il Cervello è più esteso del Cielo

Emily Dickinson





“The brain is wider than the sky...”



Emily Dickinson (1830-1896)

*Il Cervello - è più esteso del Cielo -
Perché - mettili fianco a fianco -
L'uno l'altro conterrà
Con facilità - e Te - in aggiunta -
Il Cervello è più profondo del mare -
Perché - tienili - Azzurro contro Azzurro -
L'uno l'altro assorbirà -
Come le Spugne - i Secchi - assorbono -

Il Cervello ha giusto il peso di Dio -
Perché - Soppesali - Libbra per Libbra -
Ed essi differiranno - se differiranno -
Come la Sillaba dal Suono -*

Thank you!



UNIVERSITY OF MILAN:

Silvia Casarotto
Simone Sarasso
Andrea Pigorini
Mario Rosanova
Adenauer Casali
Matteo Fecchio
Martino Napolitani



UNIVERSITY OF LIEGE:

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Marie-Aurelie
Bruno
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