Perspective on disorders of consciousness

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Google: Wlodzislaw Duch

IV International Conference „Towards standards of care for coma patients".
7-8.09.2017

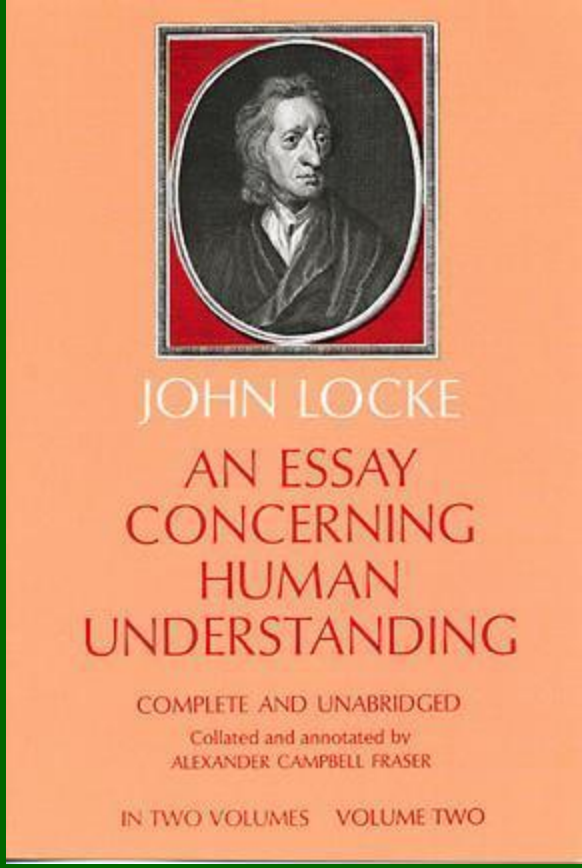
Consciousness

John Locke, *An Essay Concerning Human Understanding*, 1689. Book II, Chap. I, §19

Consciousness is the perception of what passes in a man's own mind.

Nothing mysterious, robot may also have it.
Questions:

1. Why am I conscious off?
2. What am I conscious off?
3. Can we measure consciousness?
4. What are the perspectives to restore consciousness?

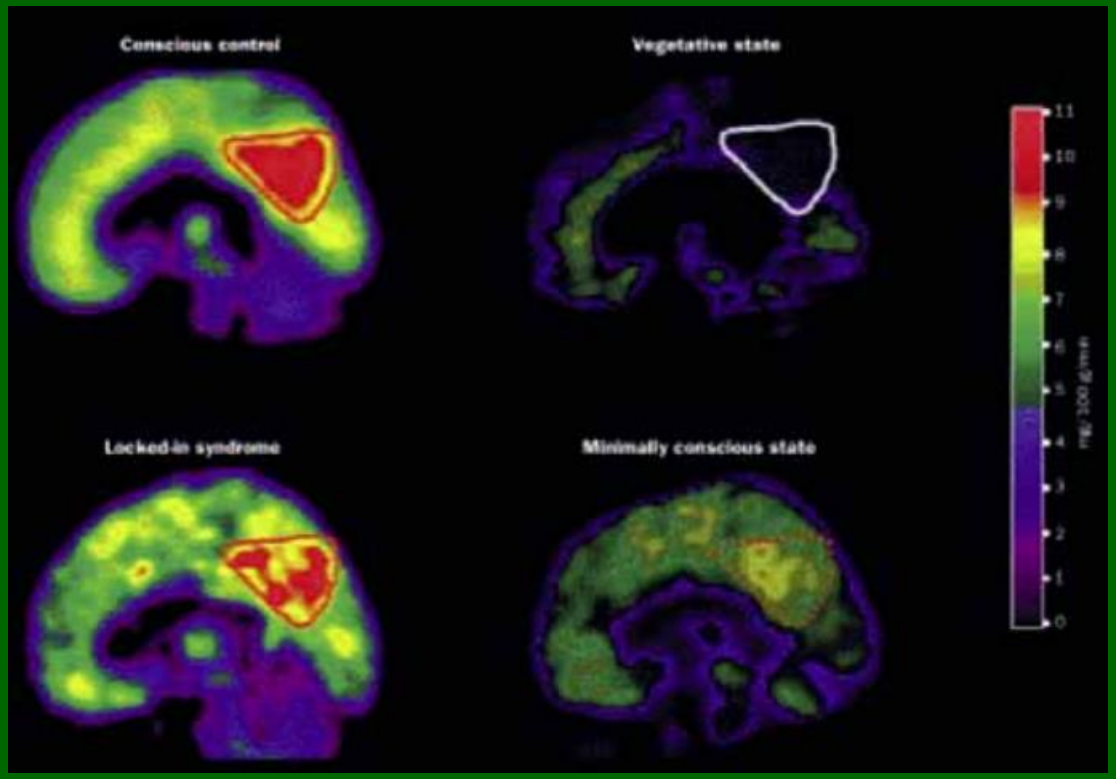


Neural Correlates of Consciousness

Normal consciousness requires distributed integrated brain activity. Complexity of structure is not sufficient: cerebellum has 80% of all neurons, and little or no contribution to conscious states.

Search for specific neural correlates of consciousness (NCC) was started by Crick and Koch (1990).

PET studies showed large differences in brain activity in normal awake subjects, locked-in subjects, minimal consciousness and vegetative states, and no activity of the dead brain.



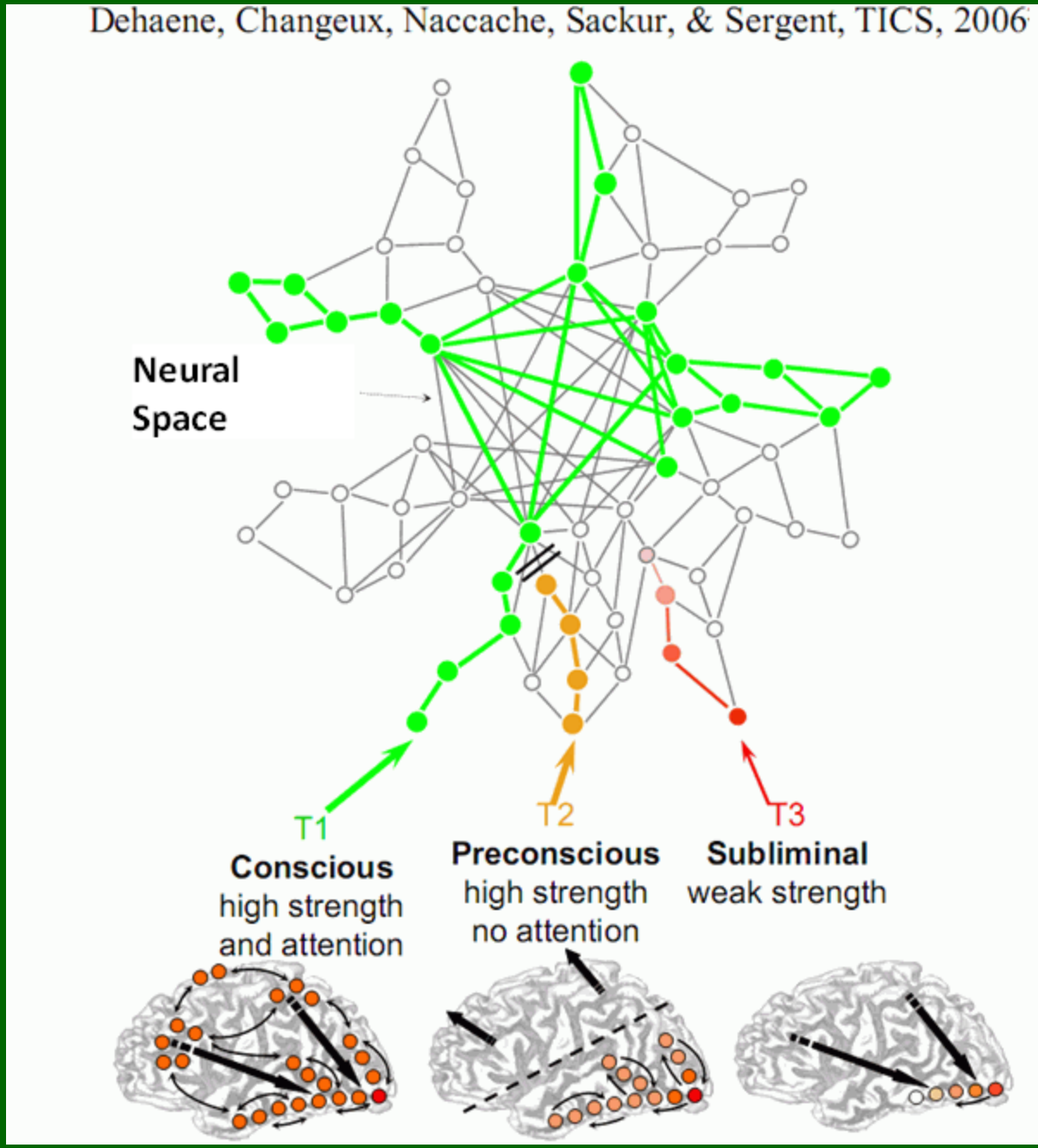
Laureys S. et al., Lancet Neurology, 2004;3:537-54

Conscious Perception

Very little of what passes In the brain is perceived.

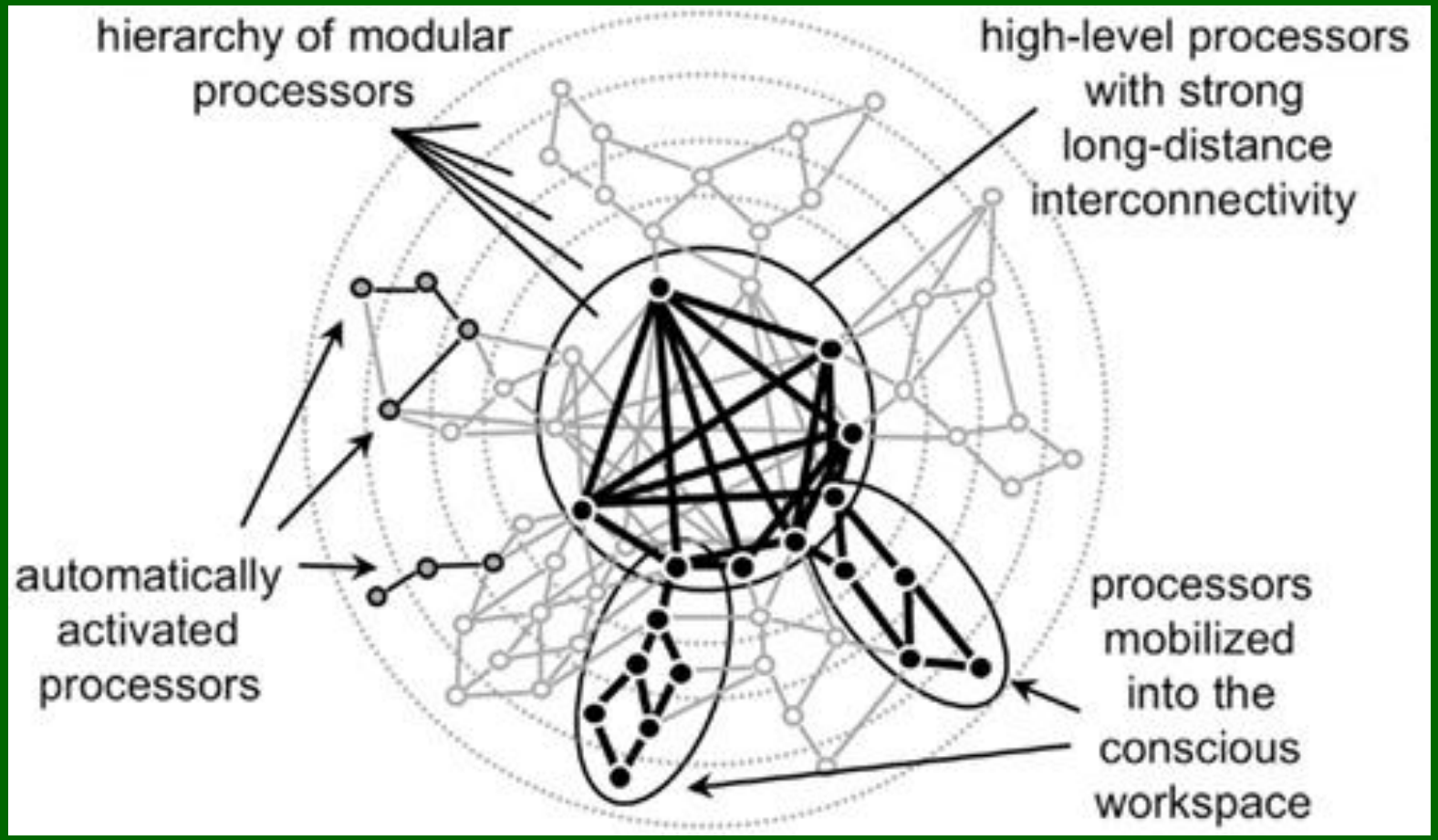
Attention + stimulation is needed to create brain states that are persistent and can be distinguished from noise.
Attention: 20 Hz
Perception: 40 Hz

C. Gilbert, M. Sigman, Brain States: Top-Down Influences in Sensory Processing. Neuron 54(5), 677-696, 2007



GNWT

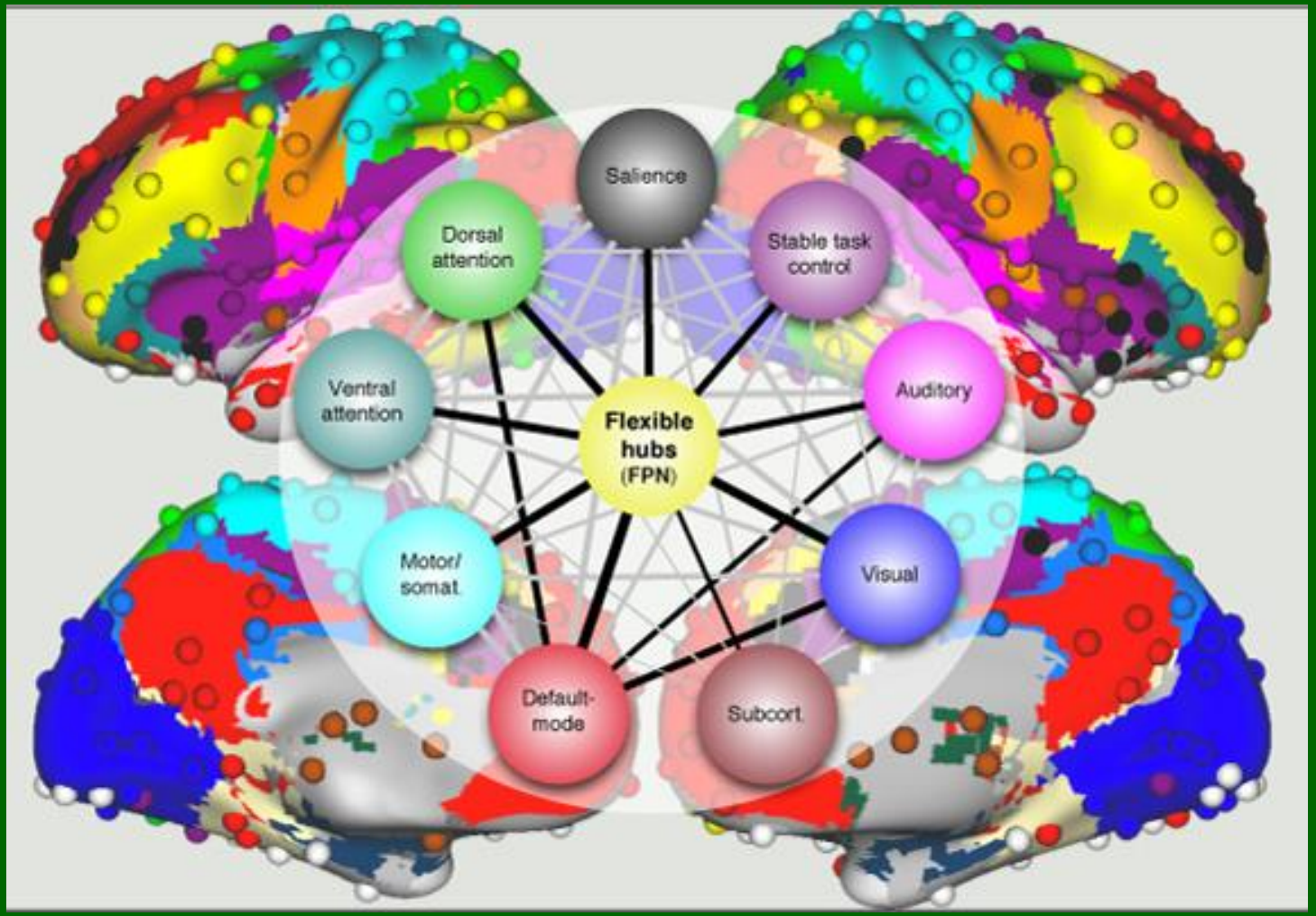
Global Neuronal Workspace Theory (Dehaene et al. 1998)



Dead core: Unresponsivie Wakefulness (UWS, VS)

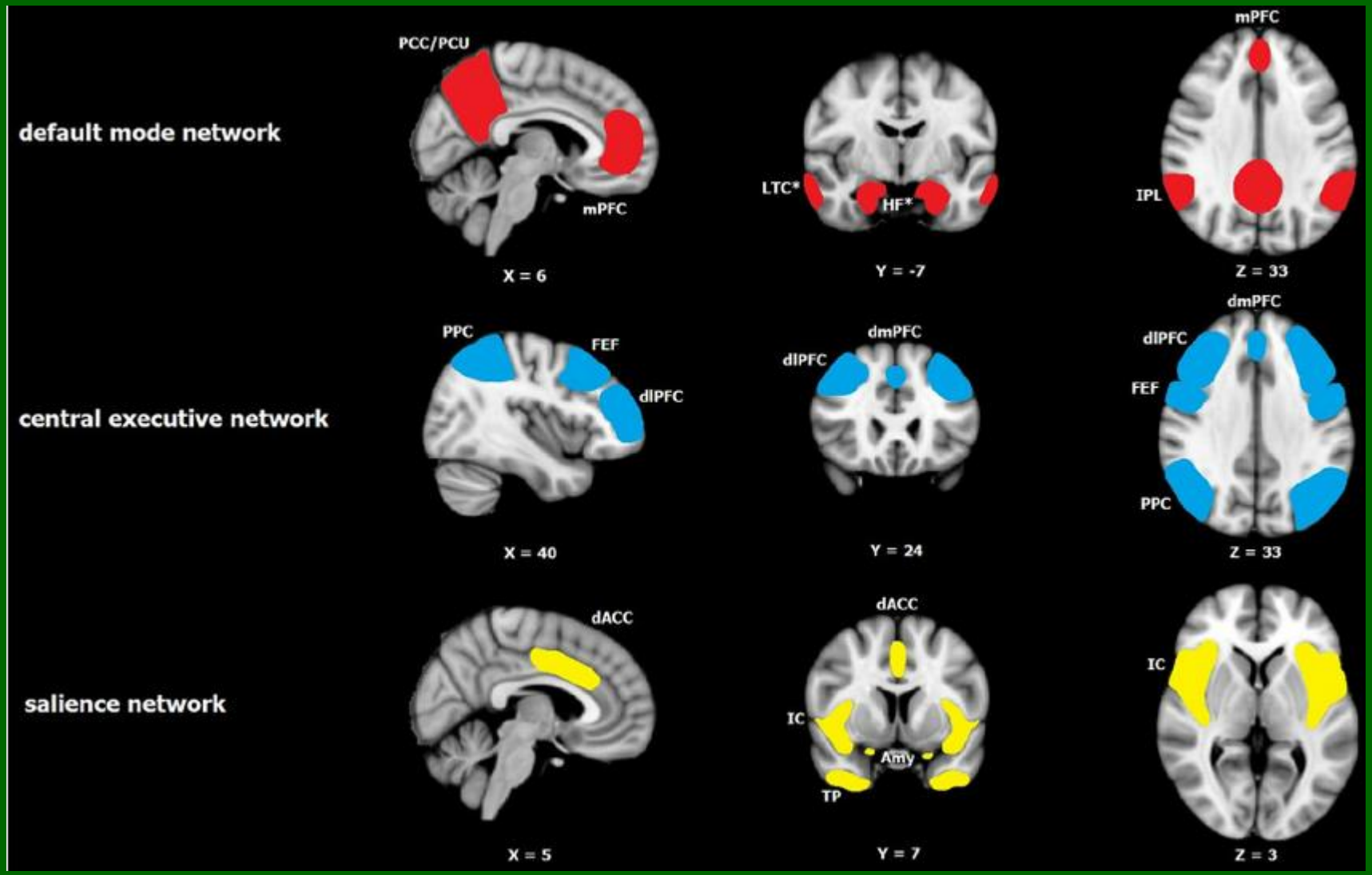
Partial core activity: MCS, continuous changes.

Neurocognitive Basis of Cognitive Control



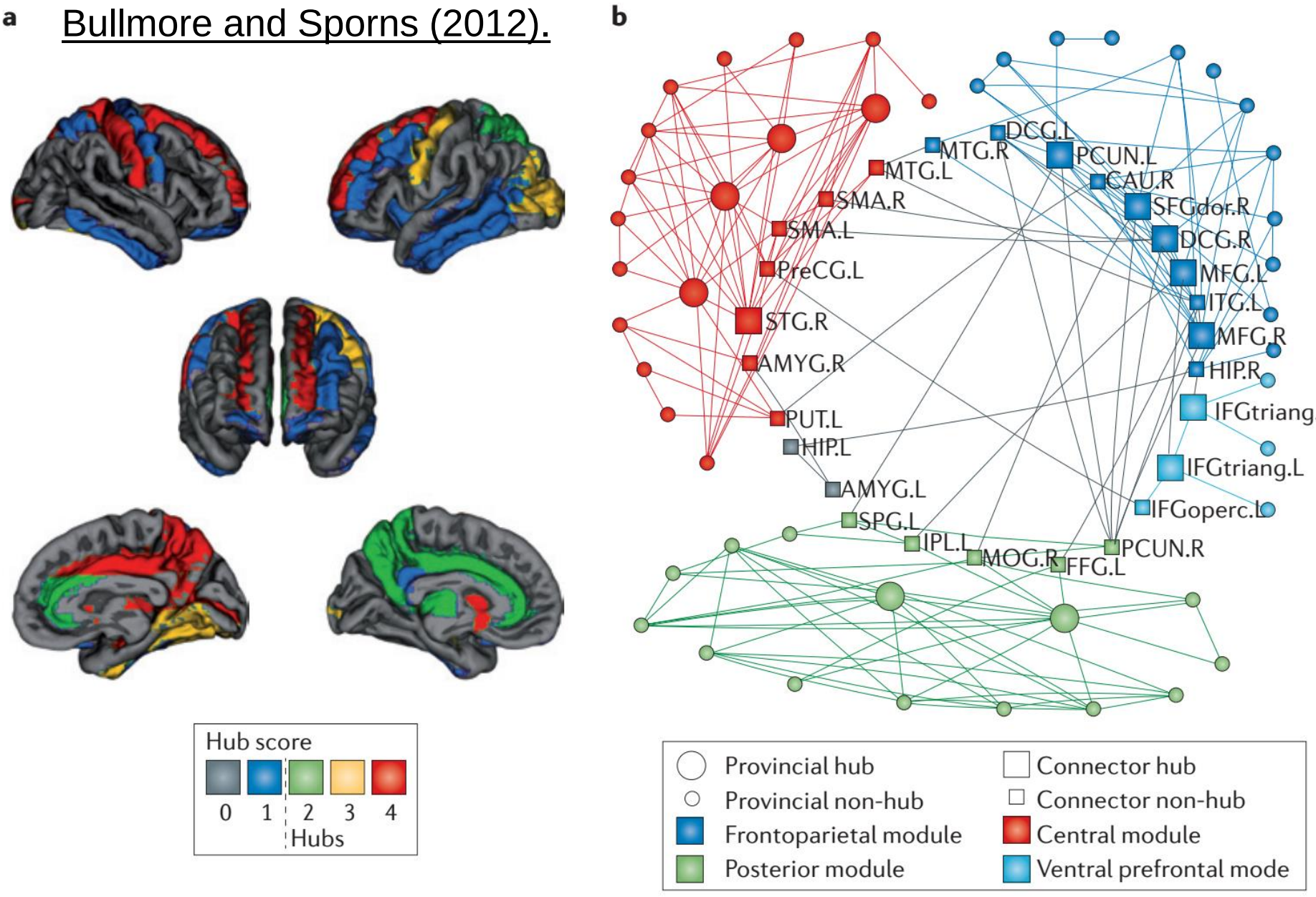
Cole M.W. et al. (2013). Multi-task connectivity reveals flexible hubs for adaptive task control. *Nature Neuroscience*; 2013

DMN, CEN and SN networks



Mulders et al. (2015)

Bullmore and Sporns (2012).

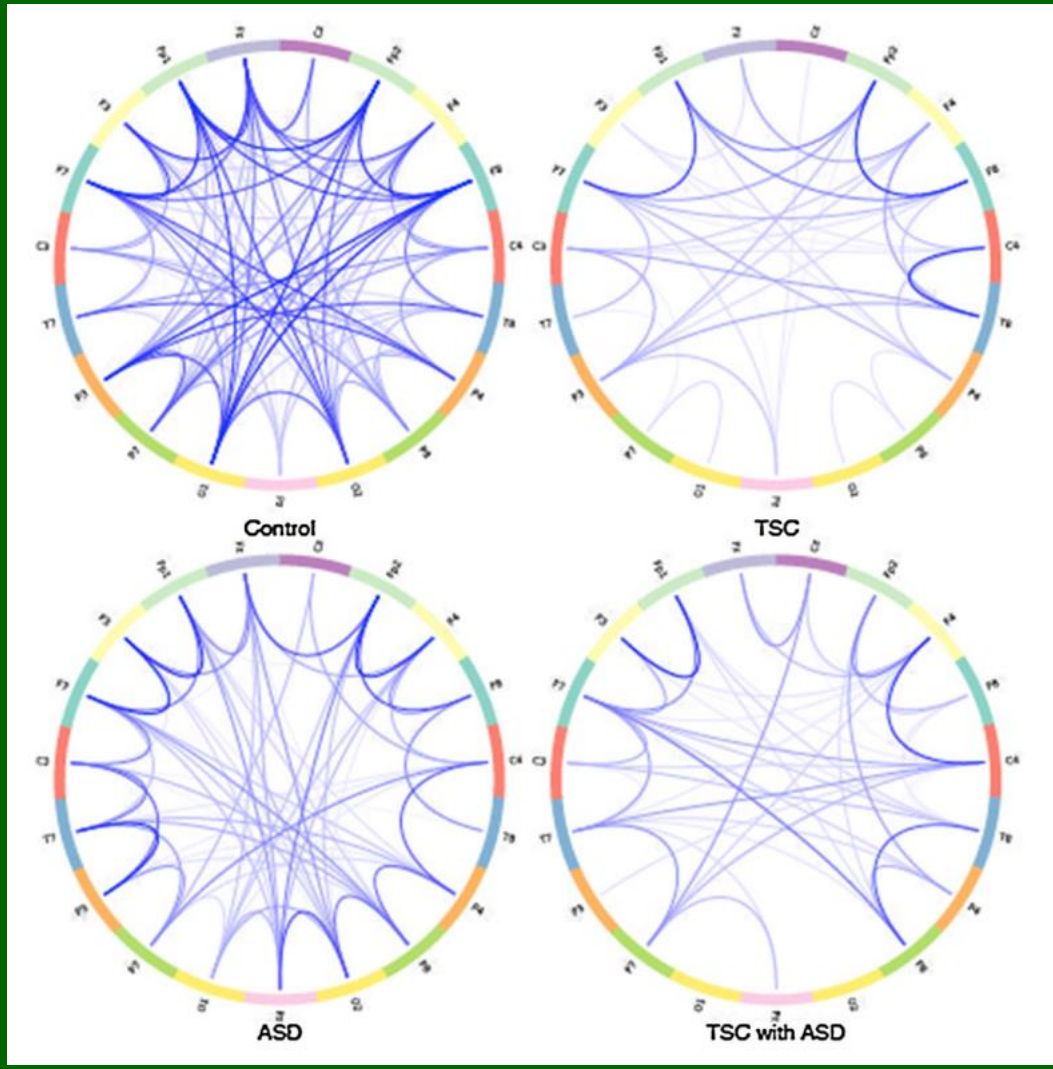


Connectome fingerprint

Comparison of connections for patients with ASD (autism spectrum), TSC (Tuberous Sclerosis), and ASD+TSC.

Weak or missing connections between distant regions prevent ASD/TSC patients from solving more demanding cognitive tasks.

Network analysis becomes very useful for diagnosis of changes due to the disease and learning, individual differences.



J.F. Glazebrook, R. Wallace, Pathologies in functional connectivity, feedback control and robustness. Cogn Process (2015) 16:1–16

Brain modules and cognitive processes

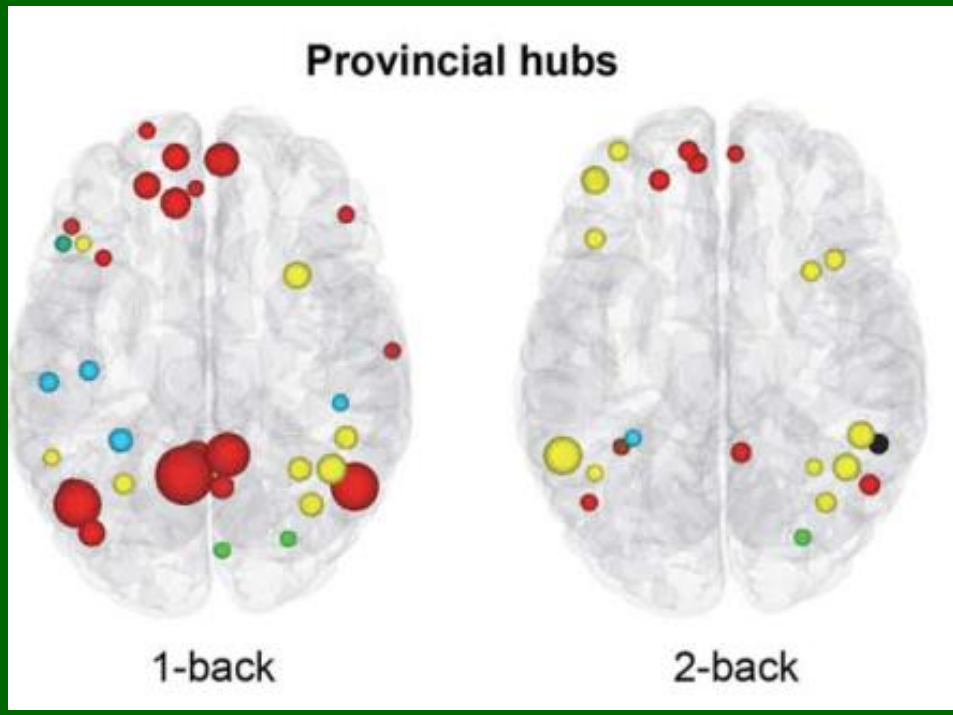
Simple and more difficult tasks, requiring the whole-brain network reorganization.

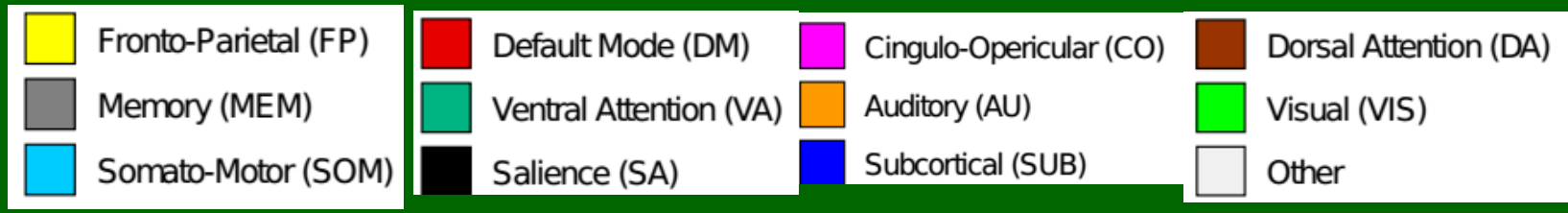
Left: 1-back local hubs

Right: 2-back local hubs

Average over 35 *participants.*

Dynamical change of the landscape of attractors, depending on the cognitive load (Khaneman system 1). Less local (especially in DMN), more global binding (especially in PFC).





Karolina Finc et al, HBM (7/2017).

Brain modules and cognitive processes

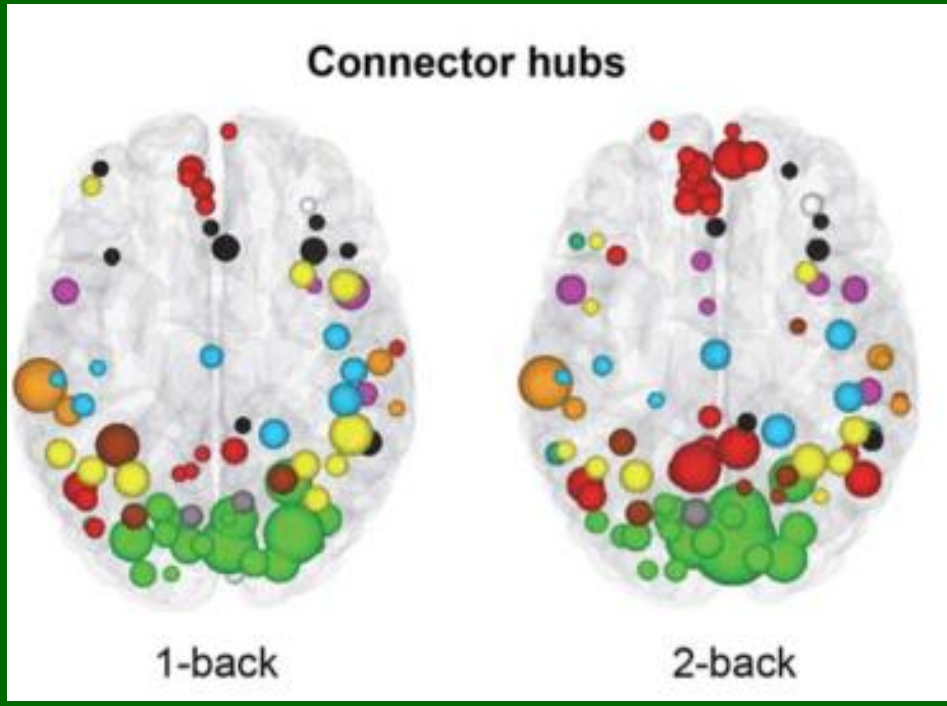
Simple and more difficult tasks, requiring the whole-brain network reorganization.

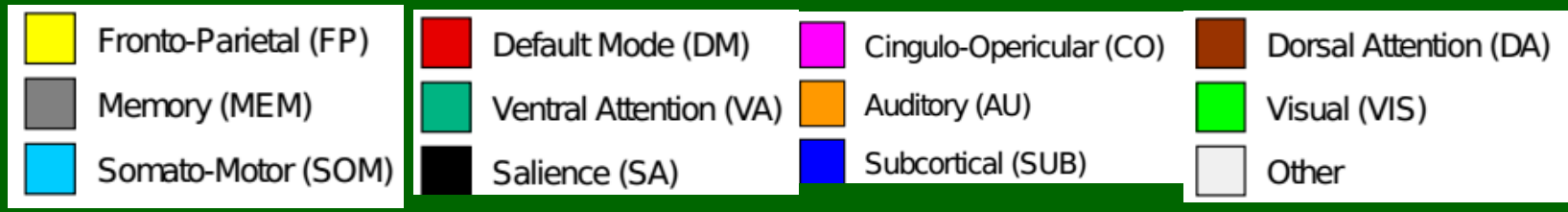
Left: 1-back connector hubs

Right: 2-back connector hubs

Average over 35 *participants.*

Dynamical change of the landscape of attractors, depending on the cognitive load (Khaneman System 2).
DMN areas engaged in global binding!

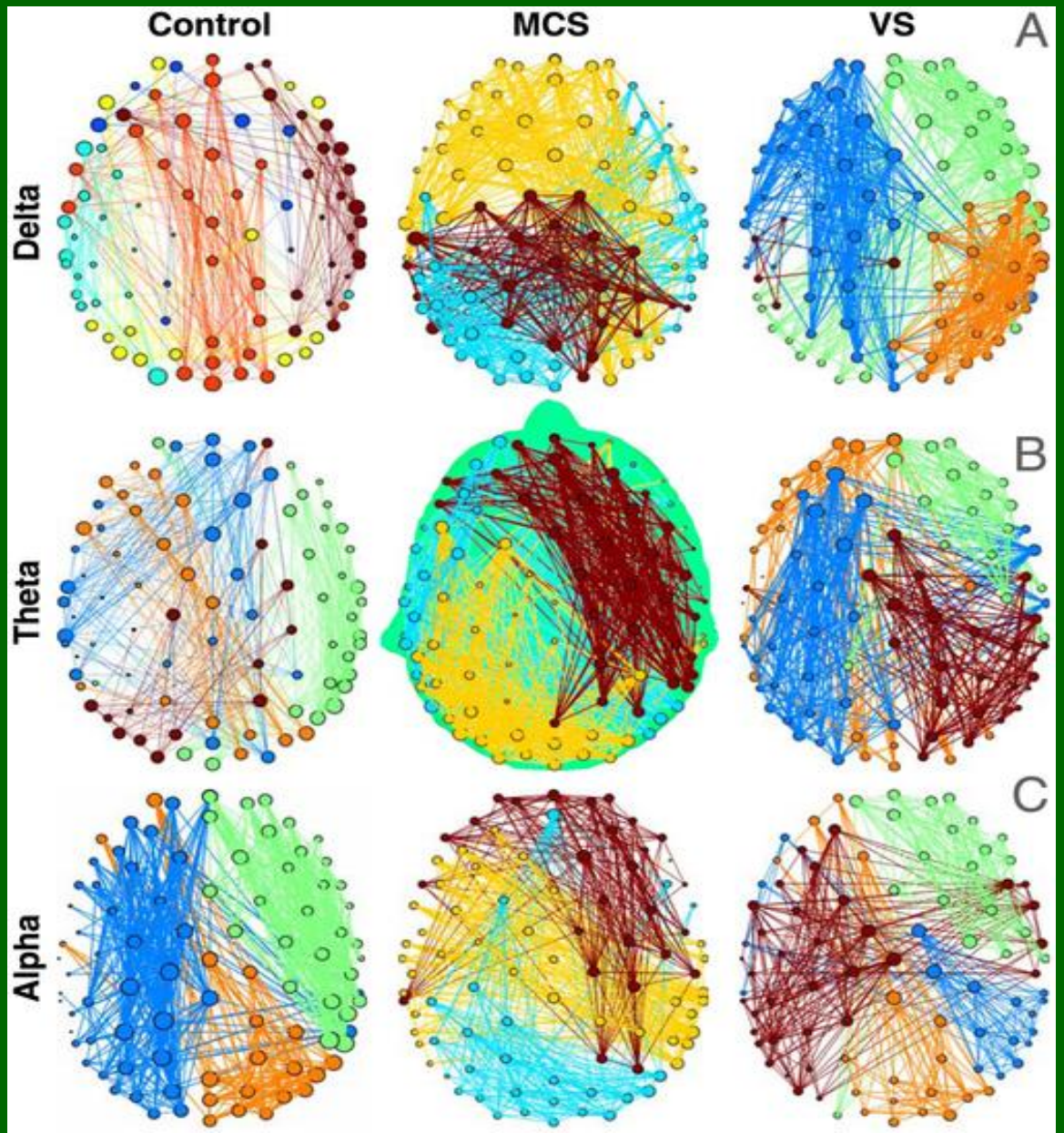




Karolina Finc et al, HBM (7/2017).

Band-wise connectivity

Weighted connectivity networks averaged by group, for α, β, δ frequency bands. Size of a node is proportional to its degree, thickness of an edge to its dwPLI (debiased weighted Phase Lag Index). Modules identified are indicated by colors.



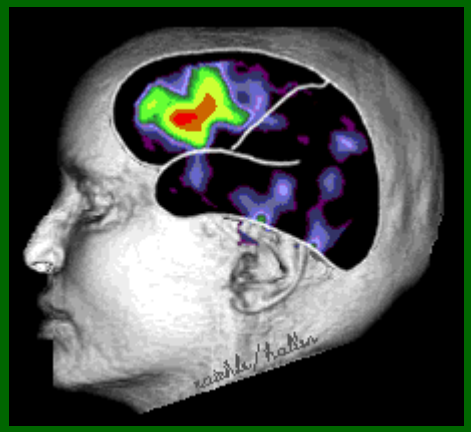
S. Chennu et al. Spectral Signatures of Reorganised Brain Networks in Disorders of Consciousness. PLOS Computational Biology 10(10): e1003887 (2014)

Brain ⇔ Mind

Objective ⇔ Subjective.

Brain ⇔ Mind.

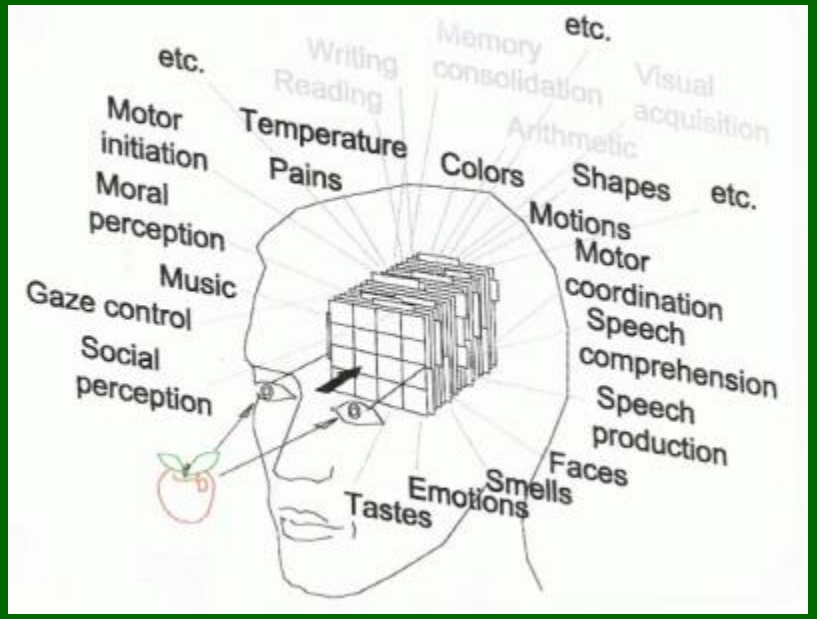
Neurodynamics describes neural activity that can be measured using such neuroimaging techniques as EEG, ERP, MEG, NIRS-OT, PET, fMRI …



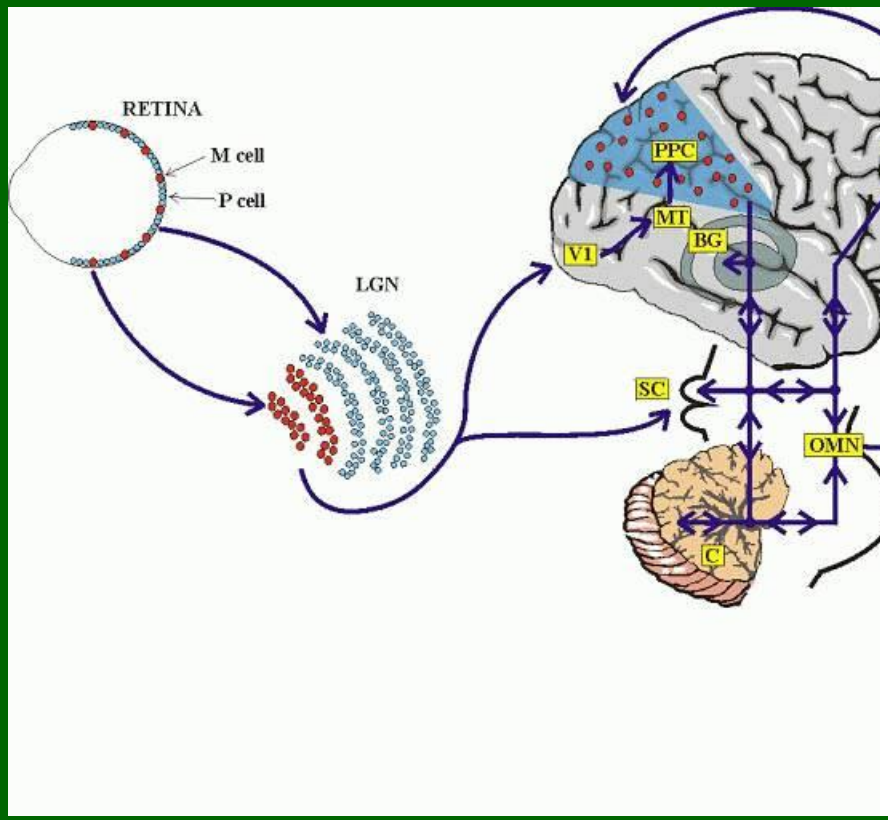
Describe mental states specifying psychological space based on dimensions that represent qualities of experience.

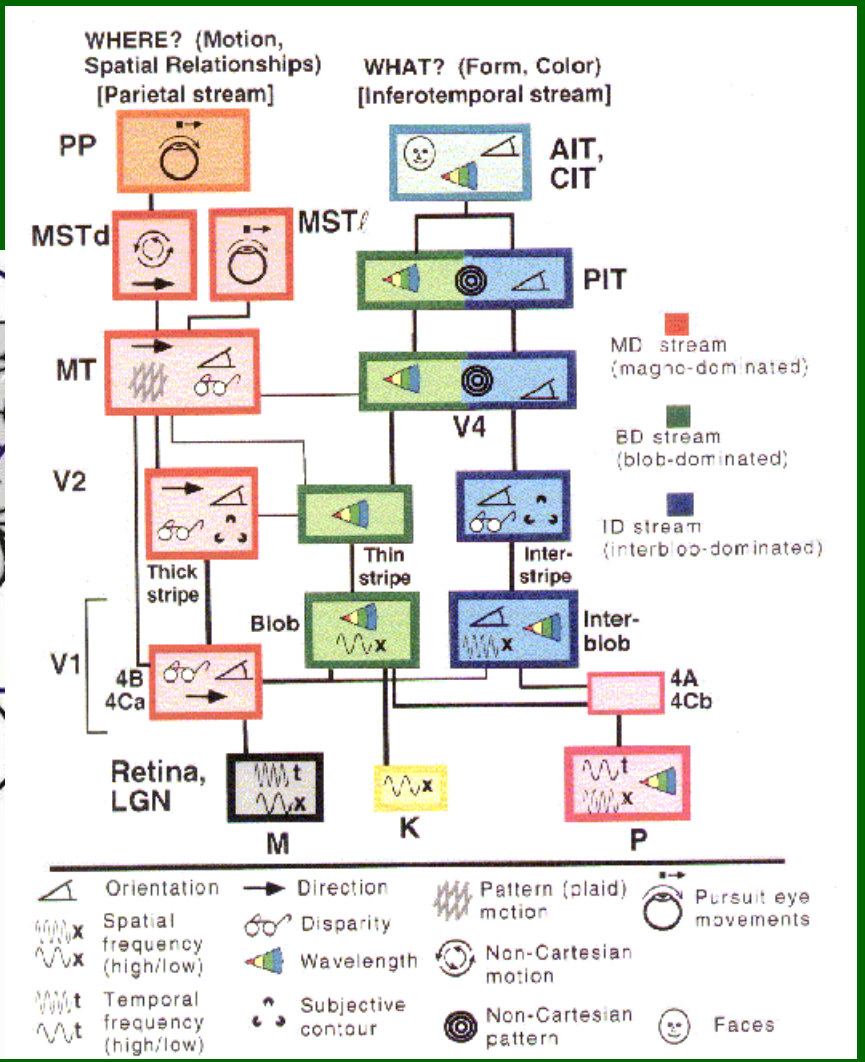
Such mapping has been the dream of many psychologist (Levin, Kelly, Shepard).

Unusual brains states (drugs, dreams, TMS) induce strange experiences, imagery, hallucinations.
DOC are unusual.



Vision





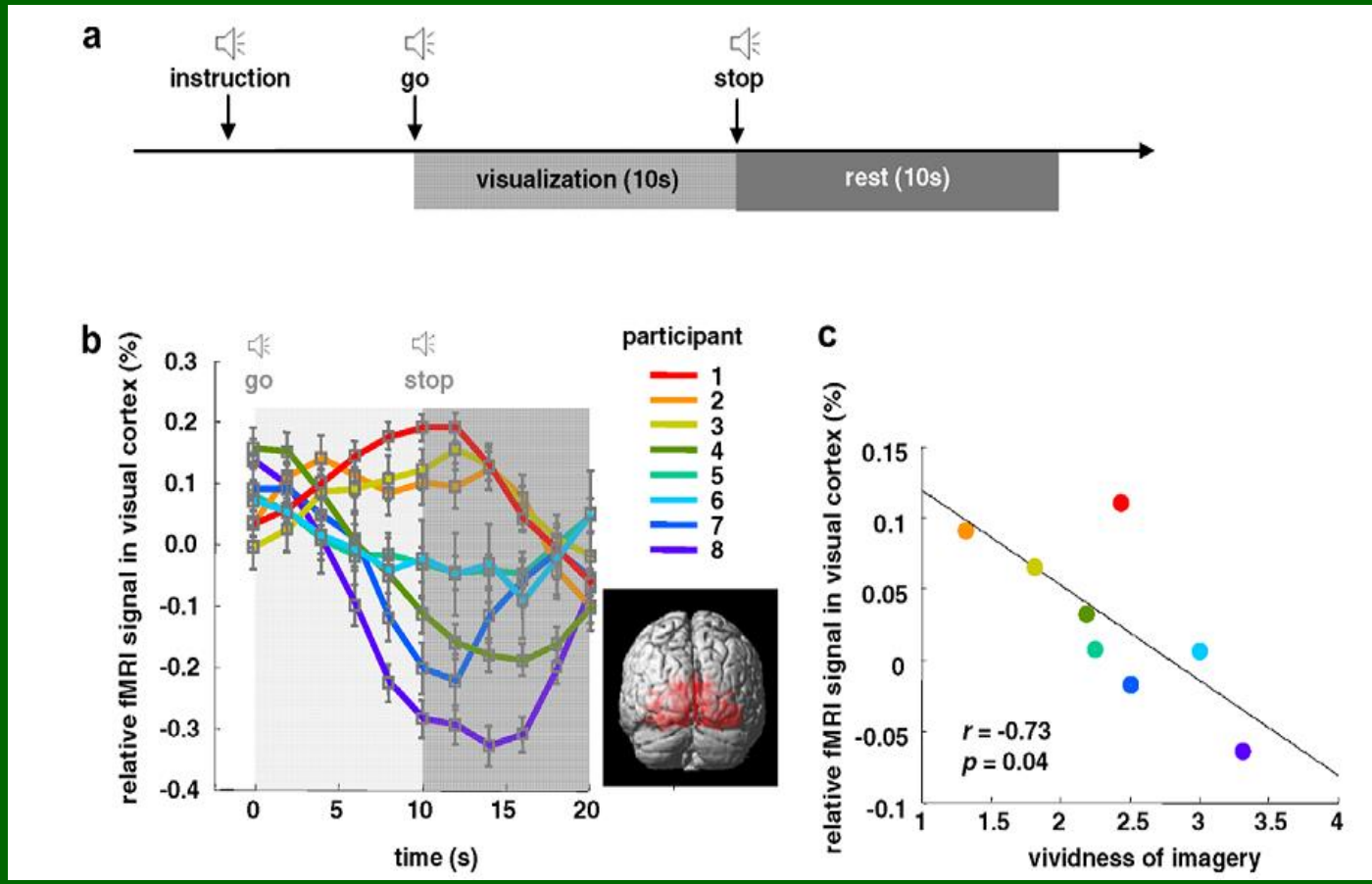
- How far does the signal from retina gets?
- If it creates strong, persistent state, stable for at least fraction of a second other parts of the brain may act on it, categorize it, initiate motor response, make a verbal comment, follow association.

Visual imagery

Content of conscious perception is in the whole brain.

Activation of V1 by top-down processes requires PFC and PC inputs.

Maybe external DCS or TMS or DBS stimulation can also facilitate it.



Results of the Vividness of Visual Imagination (VVIQ) questionnaires and V1 activity measured by fMRI are strongly correlated: some details are in V1.
Cui, X et al. Vision Research, 47, 474-478, 2007

Neural screen for vision

Consciousness of inner patterns/images.

Visual cortex = neural screen for images.

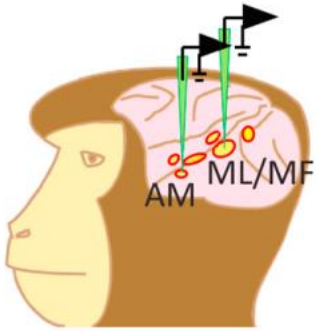
Auditory cortex = screen for auditory impressions.

Conscious reports = description, labeling of brain patterns.

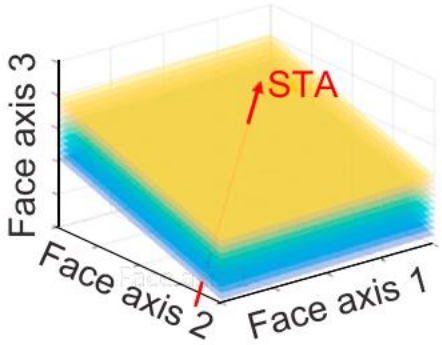
Monkeys may only gesture, not talk.

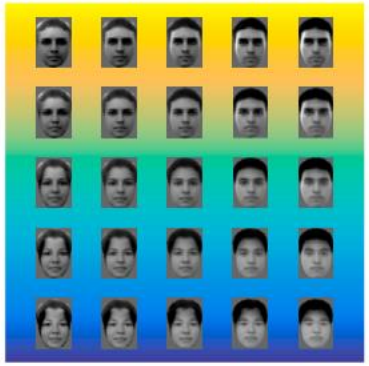
L. Chang and D.Y. Tsao, "The code for facial identity in the primate brain," *Cell*, doi:10.1016/j.cell.2017.05.011, 2017

1. We recorded responses to parameterized faces from macaque face patches

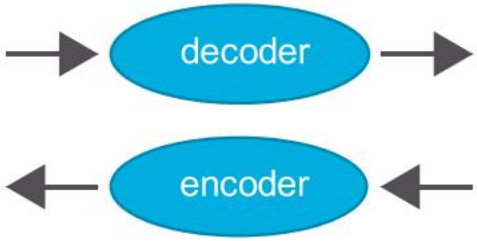


2. We found that single cells are tuned to single face axes, and are blind to changes orthogonal to this axis



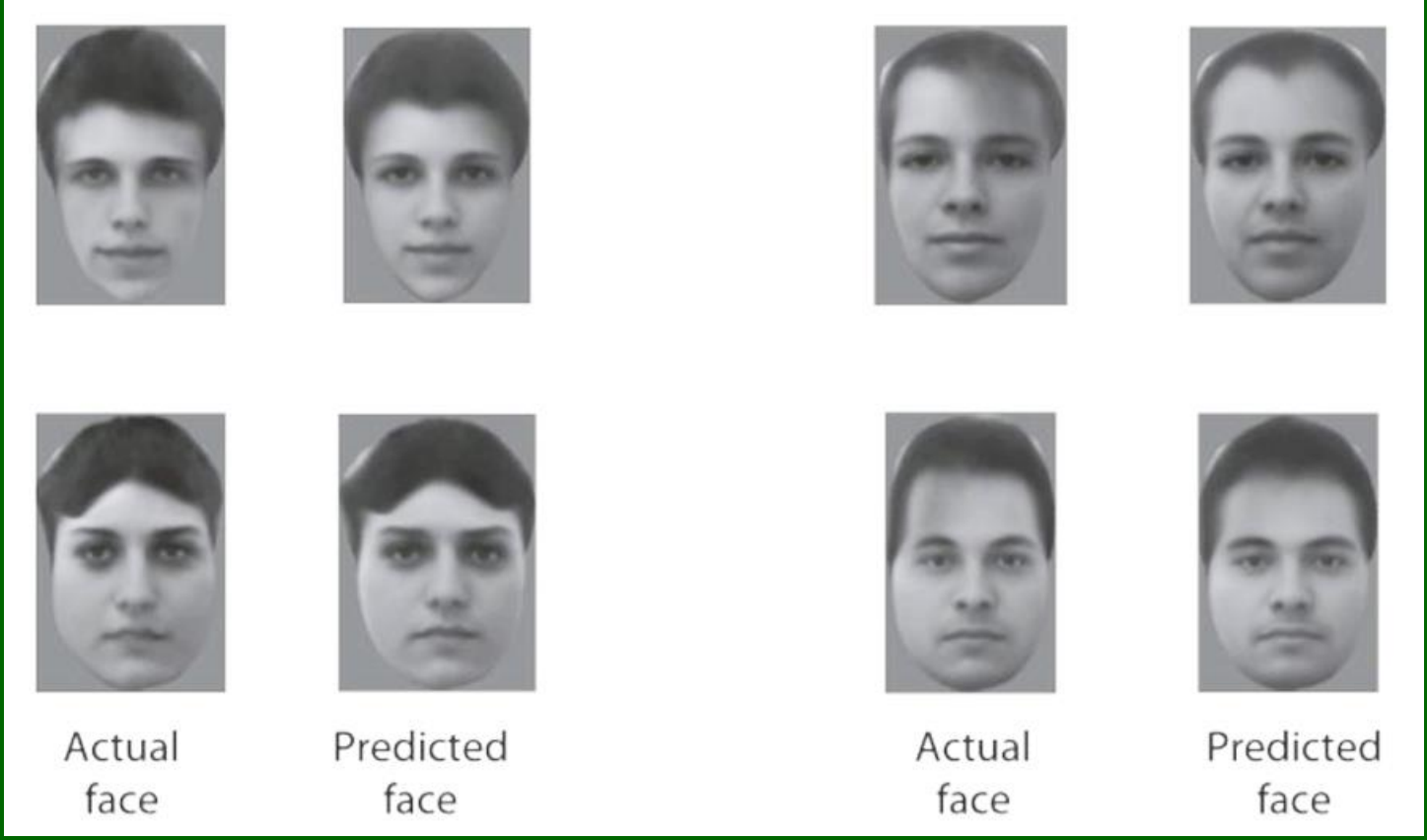


3. We found that an axis model allows precise encoding and decoding of neural responses



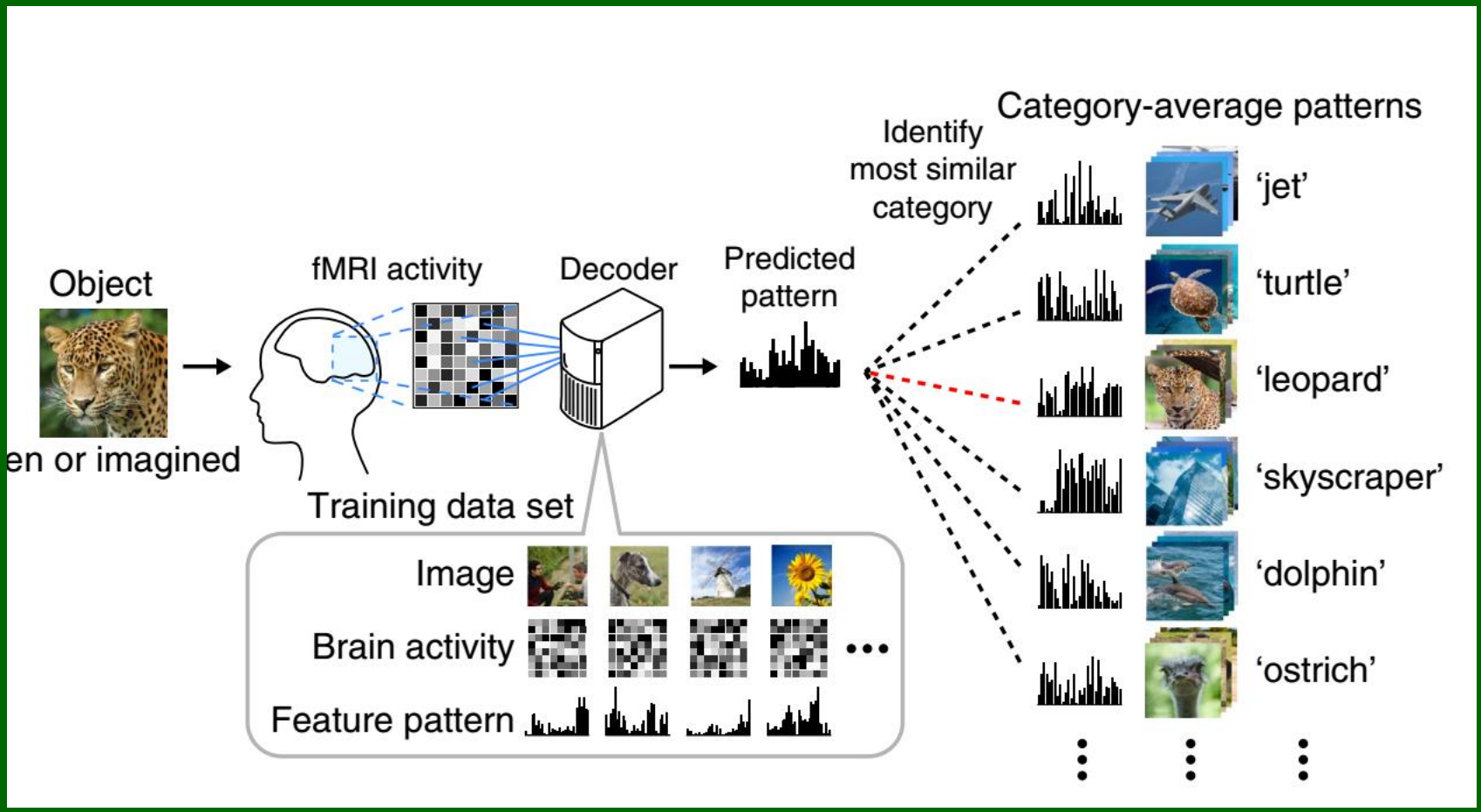
Conscious Perception

205 neurons in visual areas are sufficient to recreate what monkey has seen. In humans even content of dreams may be recreated.



Brain activity ⇔ Mental image

fMRI activity can be correlated with deep CNN network features;
using these features closest image from large database is selected.
Horikawa, Kamitani, Generic decoding of seen and imagined objects using hierarchical visual features. Nature Communnications 5/2017.



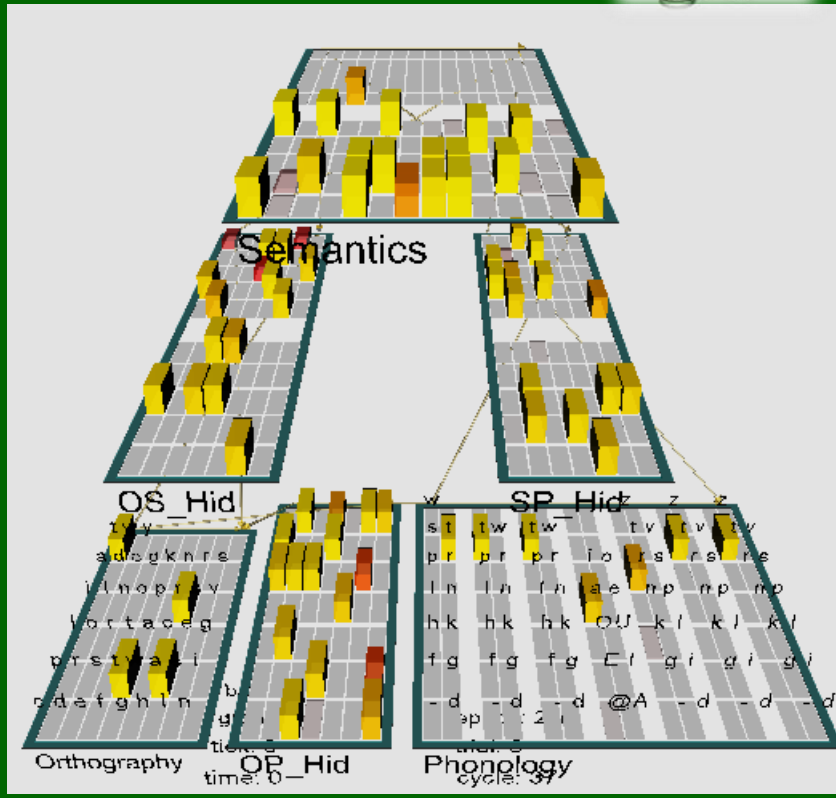
Labeling neural states

Neural simulation software:

B. Aisa, B. Mingus, R. O'Reilly, The emergent neural modeling system. Neural Networks, 2008.

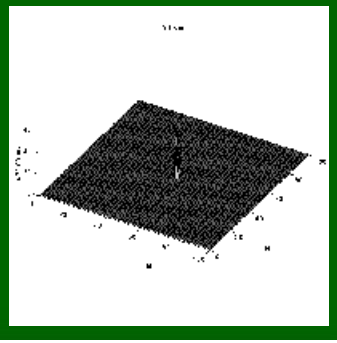
3-layer model of reading:

Recurrent neural network (RNN) with orthography, phonology, and semantic layer = activity of 140 microfeatures that define concepts by distribution of their activations.



Activity on the “neural screen” (semantic layer) may be detected and associated with words or actions if it persists for some time, attracted to specific pattern, otherwise it cannot influence speech or other brain areas. Sequence of attractor states can be labeled by the activity of phonological layers, creating conscious stream of verbal comments on internal state.

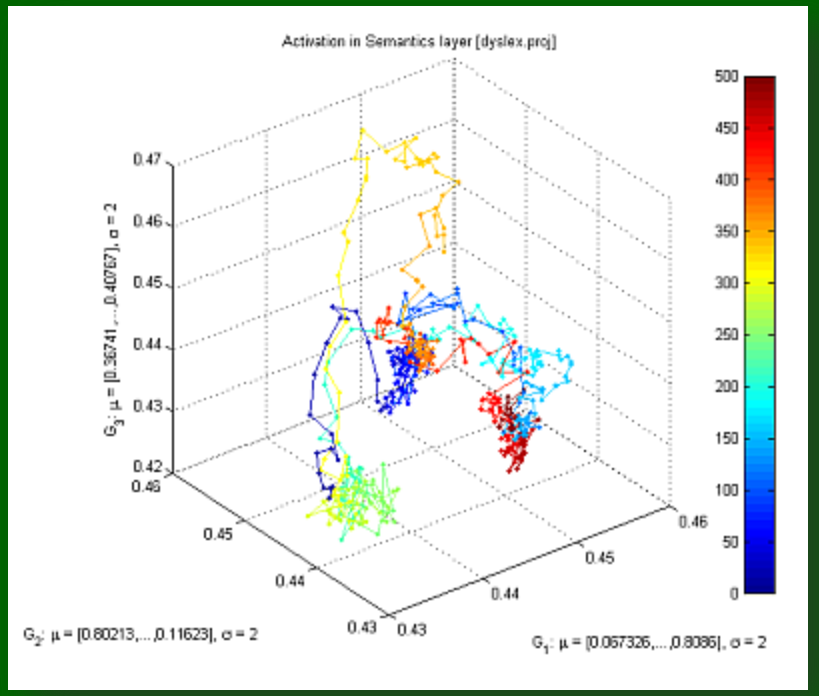
Basins of attractors



Groups of neurons synchronize, become highly active, these activations fluctuate around some specific distributions, inhibiting competing groups of neurons.

Normal case: relatively large, easy associations, fast transitions from one basin of attraction to another, creating “stream of consciousness”.

Brain has about 3 mln minicolumns in the cortex alone, corresponding to units in computational model, so this is a huge space. Here point ⇔ 140D vector.



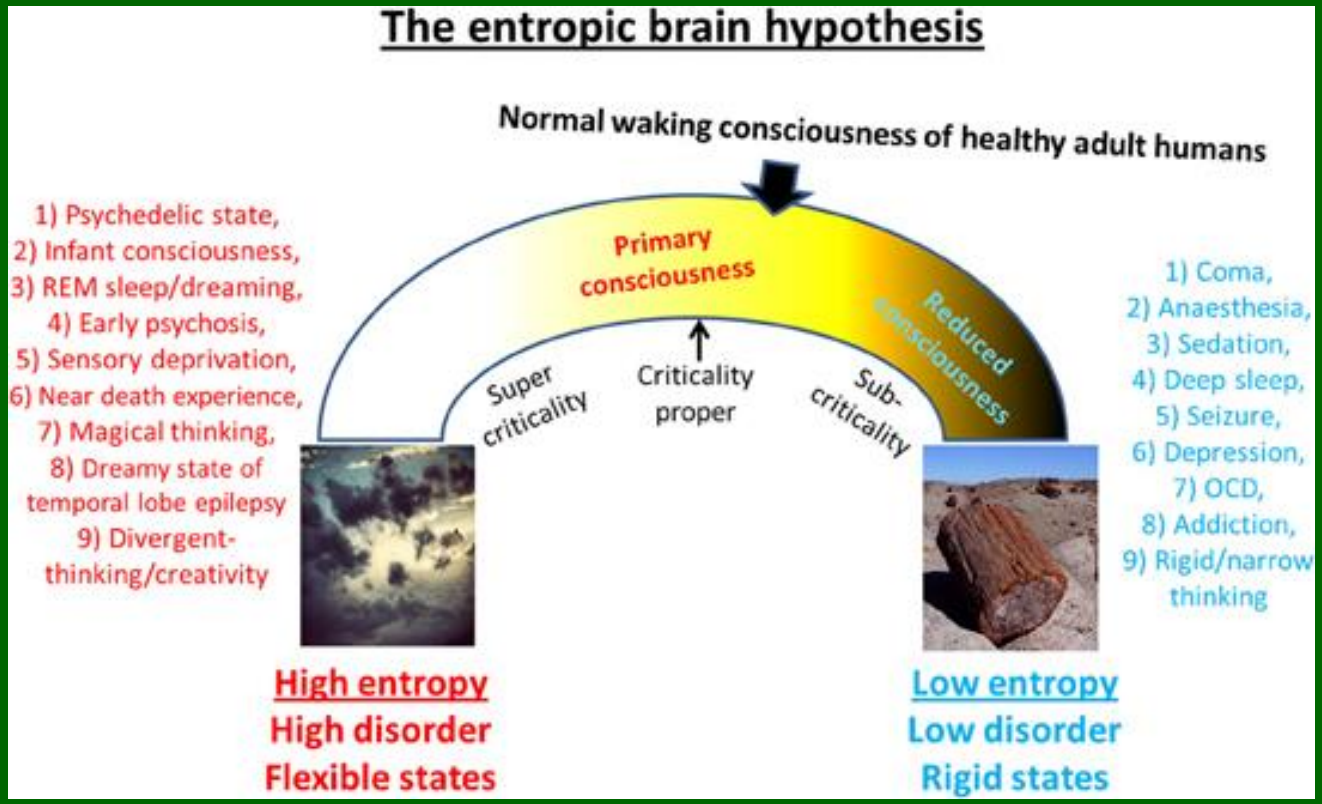
Basins of attractors represent available mental states.
Patterns of activity in each attractor basin is associated with words or actions.
Attractors shrink and vanish as neurons desynchronize due to the fatigue; this allows other neurons to synchronize, leading to new mental states (thoughts).

Measuring consciousness

How to quantitatively measure the level of consciousness in people during anesthesia, epilepsy, coma, disordered states of consciousness, in infants, various animals and machines?

Complexity of neurodynamics: not too chaotic, not too regular.

Several attractor states linking many brain areas, medium entropy.

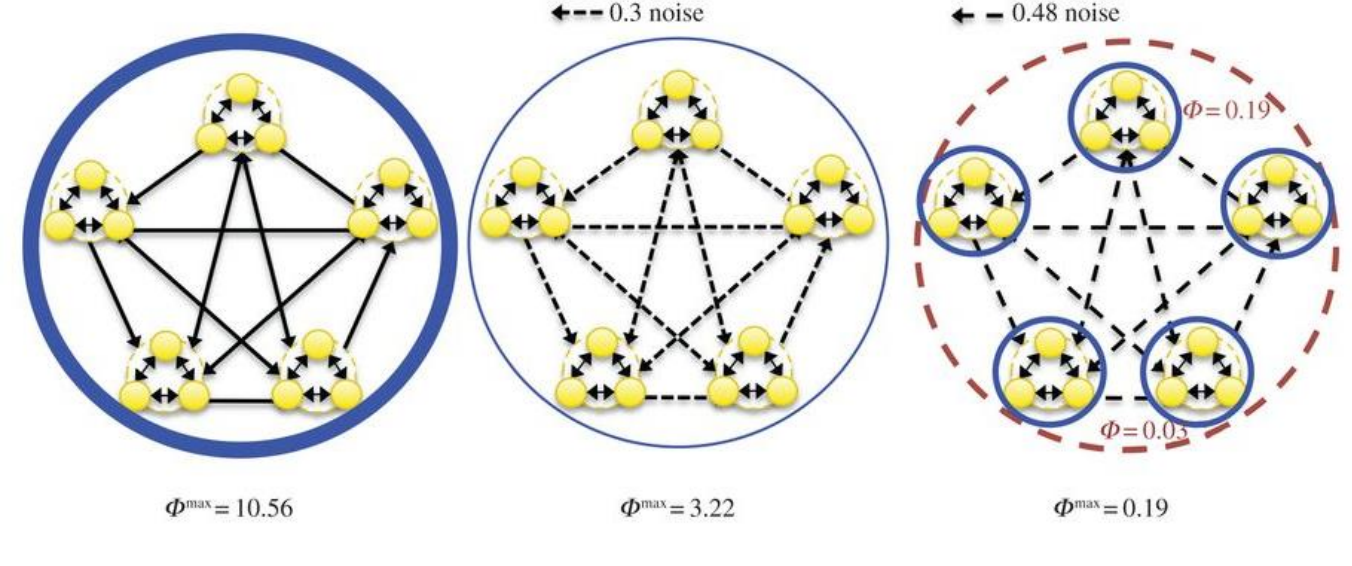


Integrated Information Theory

Information integration theory of consciousness (IITC, Tononi, Edelman, Science 1998) defines *integrated information* (F) measure, generated by the neural system, balancing wide integration and information richness.

Seth (2011) proposed causal density, calculated as the fraction of interactions among neural groups that are casually significant.

Tononi, G; Koch, C. (2015). Consciousness: Here, there and everywhere? Phil. Trans. Royal Society London B, 370: 20140167 .
Quantity (strength) and quality (shape) of experience is defined by the conceptual structure that is maximally irreducible intrinsically.

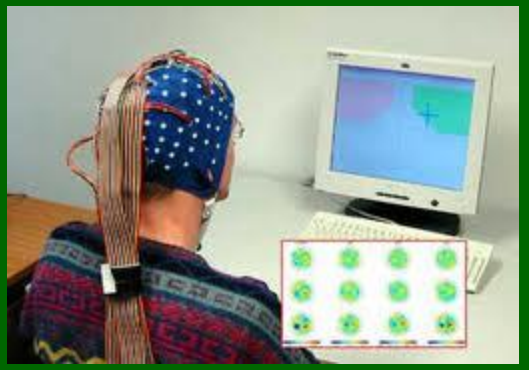


Brain-computer interfaces

Mind reading and brain stimulations are exciting and rapidly developing fields.

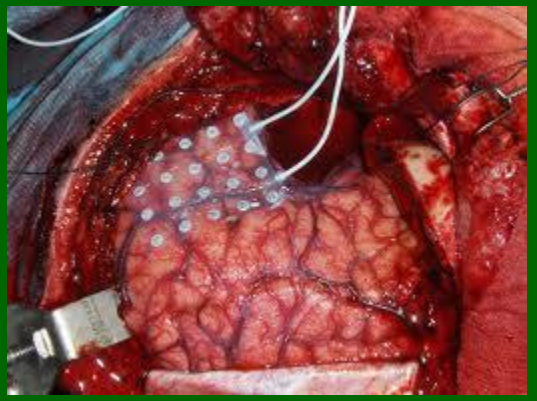
Brain-computer interfaces (BCI) read and interpret the activity of the brain.

Conscious, intentional activity is detected.



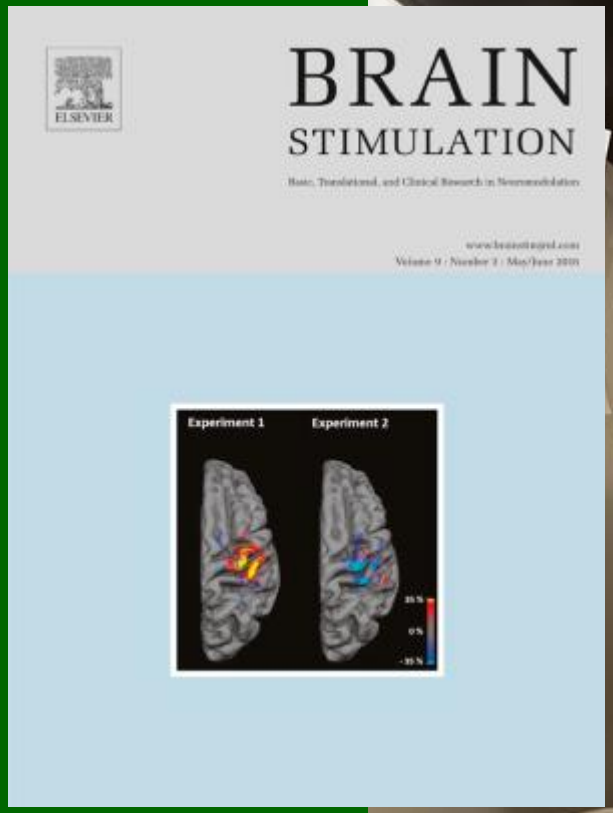
BCI development can potentially be used to communicate with people in locked-in or minimal consciousness states, but also games, mental control of vehicles, neurofeedback therapeutic procedures …

Understanding consciousness ⇔ creating artificial systems with the same functions.



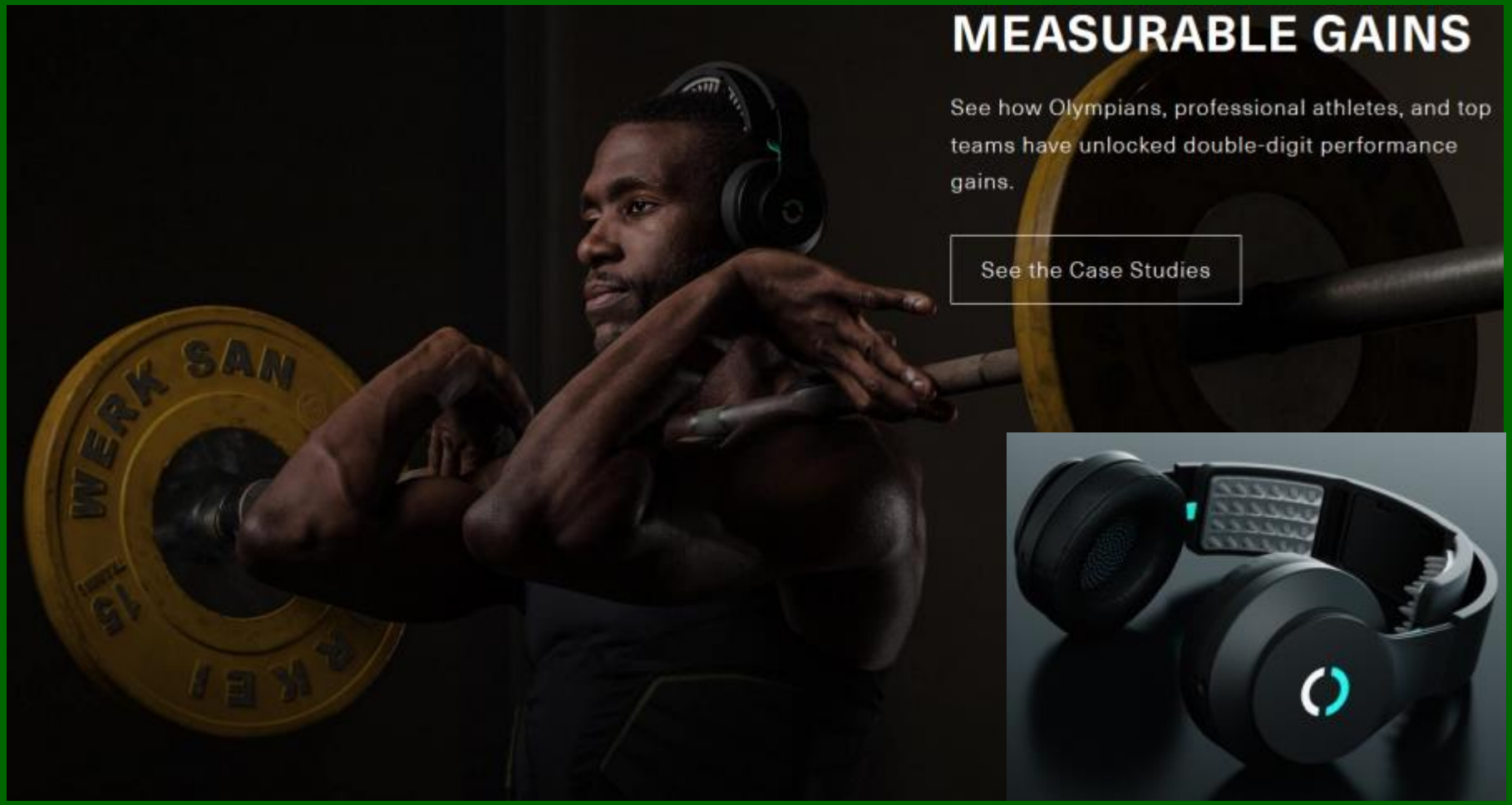
Can one detect signs of consciousness in artificial brains?
Is mental control of artificial body by coupling of human-robot brains real possibility in future?

DCS, Direct Current Stimulation



Neuropriming

Effort, stamina, force in sports requires strong activation of muscles by motor cortex. Synchronize your effort with direct current cortex stimulation.



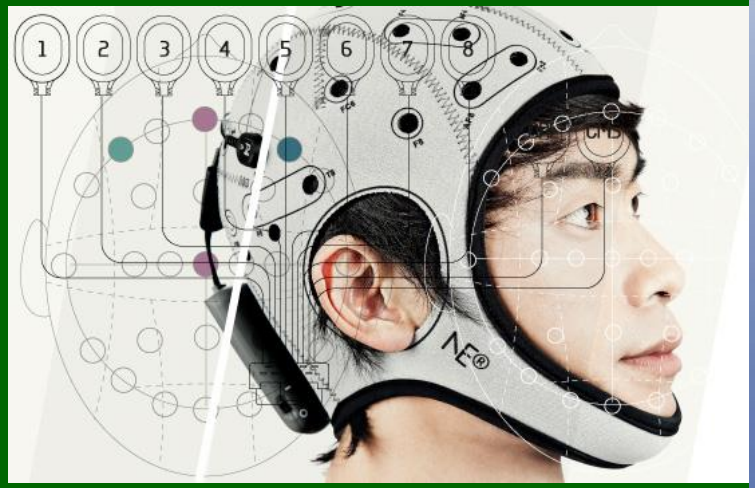
Haloneuro.com

Military applications

Engagement Skills Trainer (EST) procedures are used by USA army.

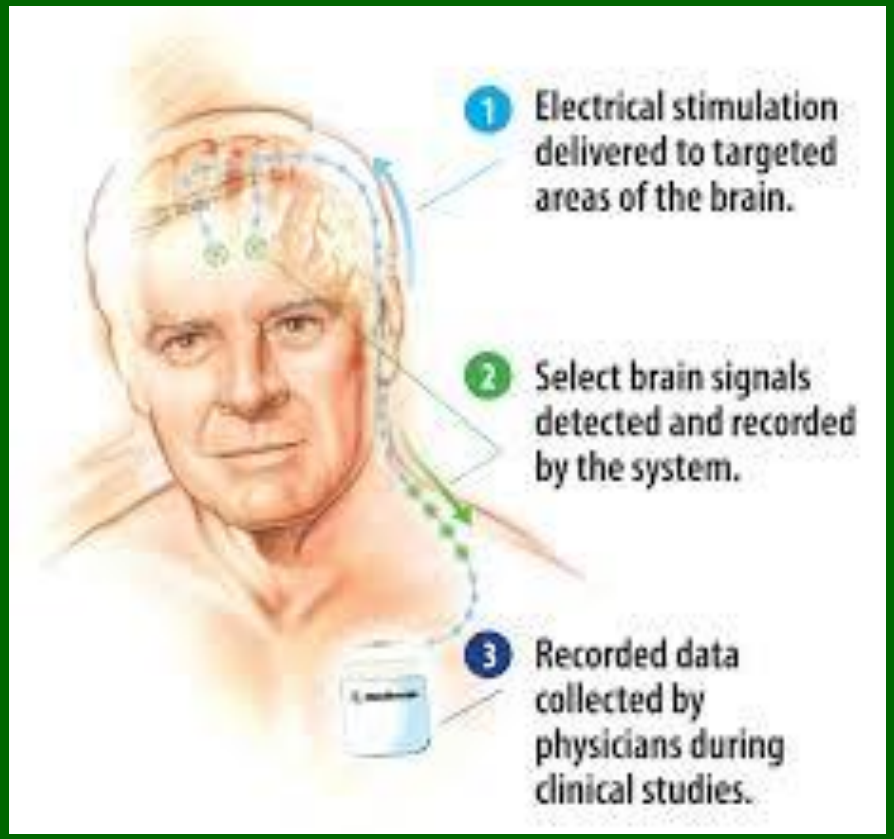
Intific Neuro-EST uses EEG analysis and mulit-channel transcranial simulation (HD-DCS with >100 electrodes) to pre-activate the brain of a novice in areas where the expert brain is active.

Real-life transfer learning … can it be used in DOC? We need to understand what DCS is doing to our brains first.



Deep brain stimulation

In case of Parkinson's disease, OCD, coma, persistent pain and many other conditions stimulation of peripheral nerves (in particular vagus nerve) and certain parts of the brain using external controller can help.
What brain functions can be consciously controlled?



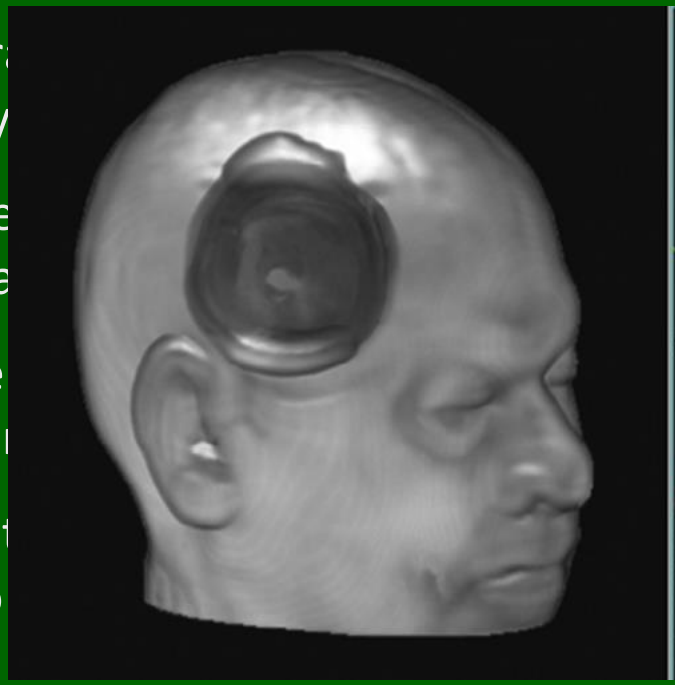
Non-invasive deep brain stimulation

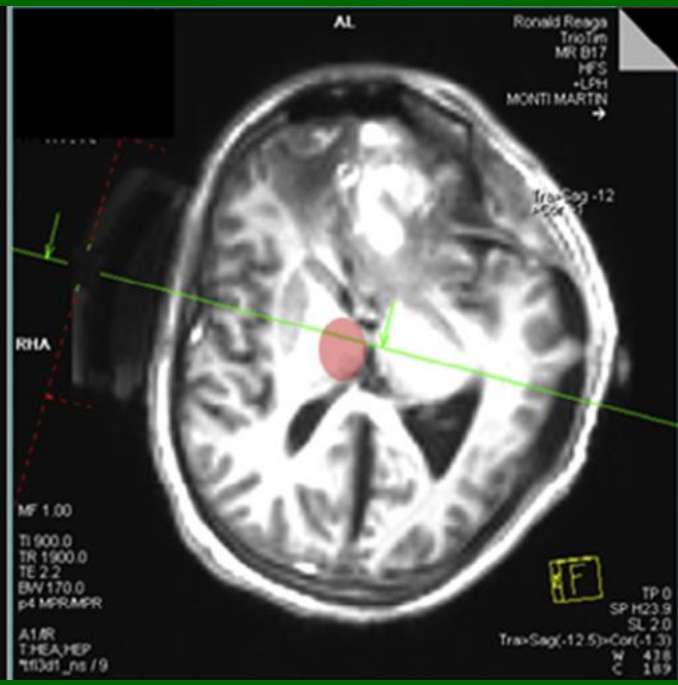
Instead of deep br
using low intensity

It can produce dire
nuclei. First clinica

Ultrasound freque
ms, repeated 10 ti

3 days post-LIFUP
5 days was able to



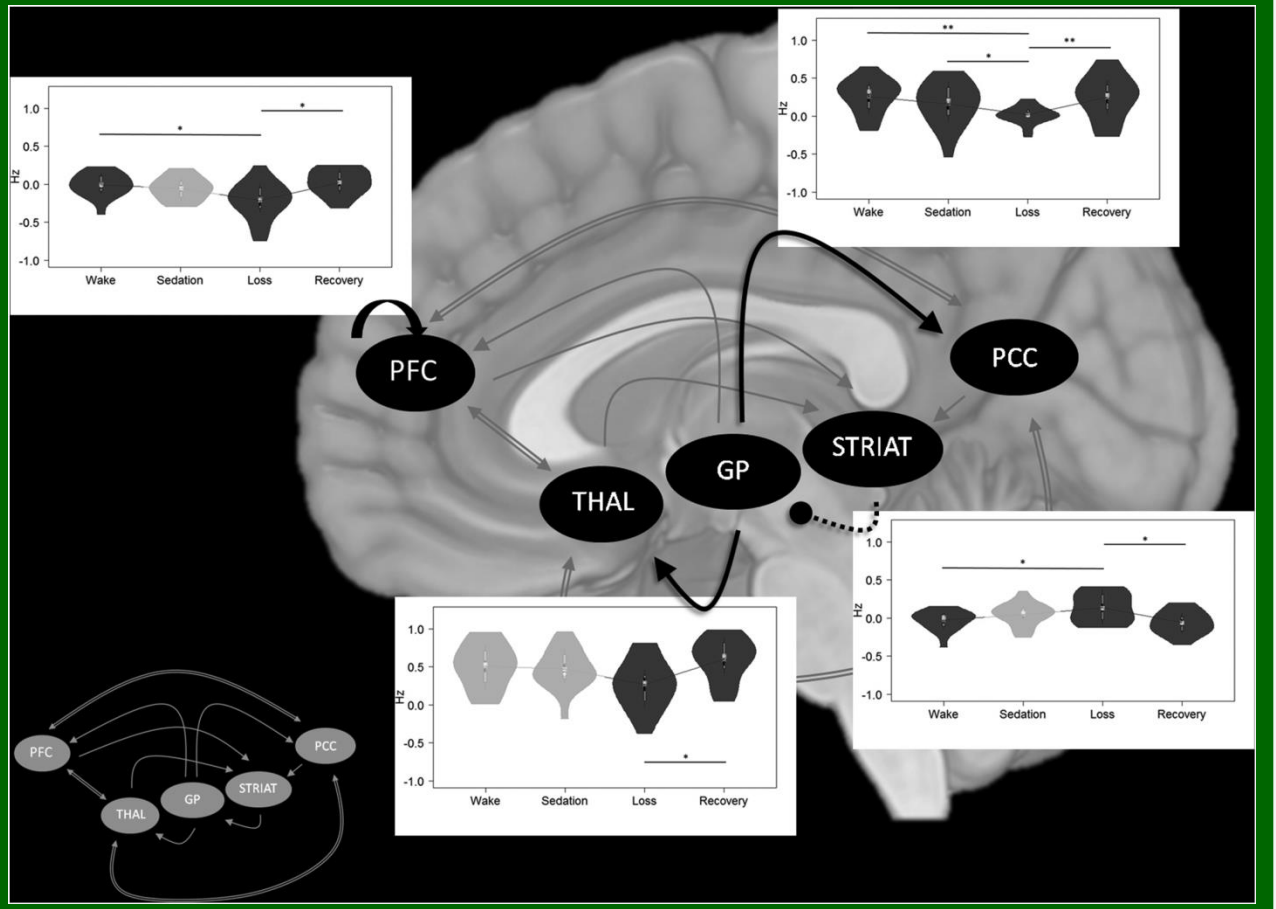


Monti, M. M. et al. (2016). Non-Invasive Ultrasonic Thalamic Stimulation in Disorders of Consciousness after Severe Brain Injury: A First-in-Man Report. *Brain Stimulation: Basic, Translational, and Clinical Research in Neuromodulation*, *9*(6), 940–941.

Baek, H., Pahk, K. J., & Kim, H. (2017). A review of low-intensity focused ultrasound for neuromodulation. *Biomedical Engineering Letters* 7(2) 135-142

Key structures in loss of consciousness

fMRI resting-state propofol-induced sedation, 7 neuronal models tested, fiting them to dynamic change in effective connectivity between specific cortical and subcortical regions by causal modeling. Loss of consciousness is marked by a breakdown of globus pallidus projections.



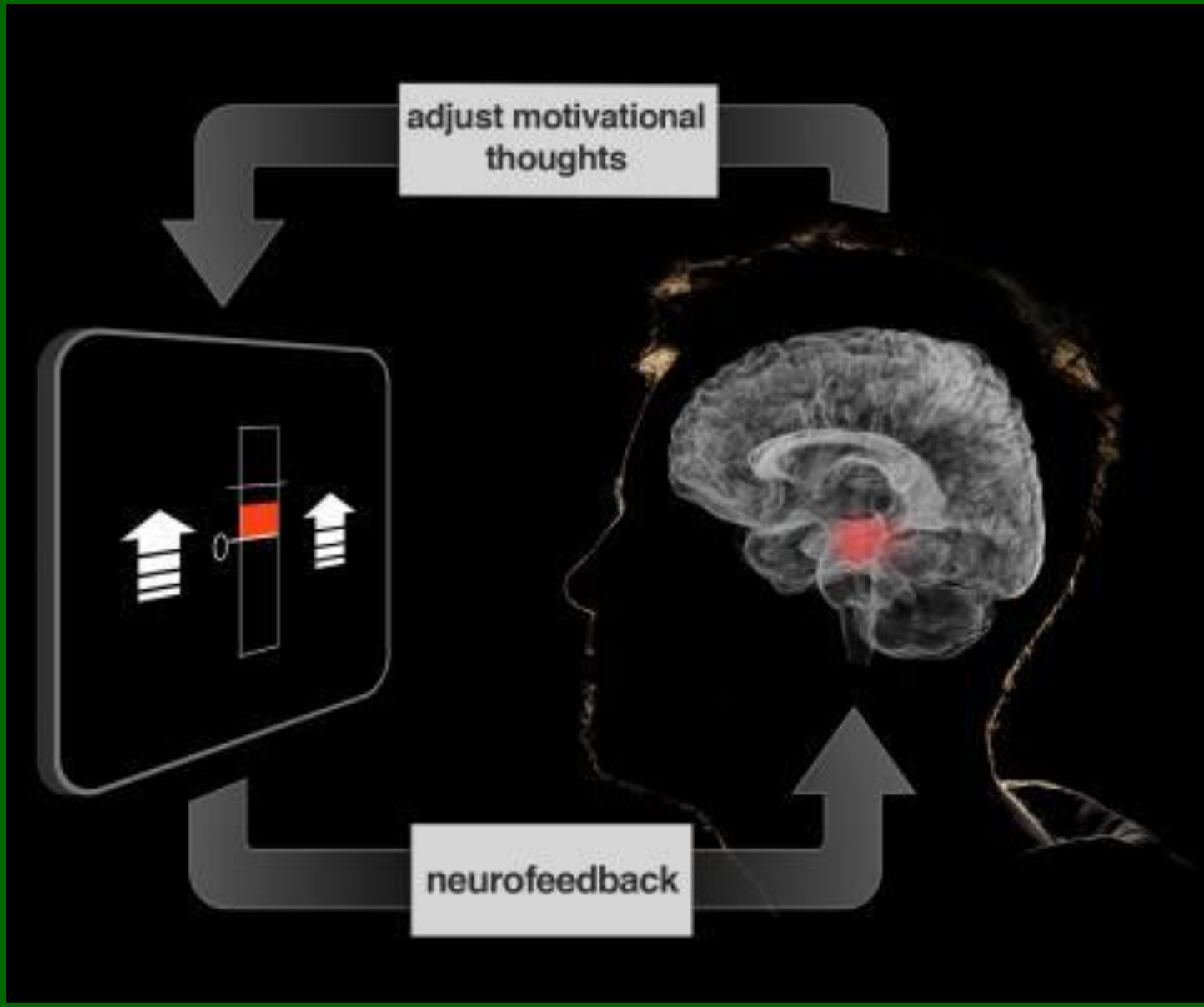
J.S. Crone et al. Testing Proposed Neuronal Models of Effective Connectivity Within the Cortico-basal Ganglia-thalamo-cortical Loop During Loss of Consciousness. Cereb Cortex. 2016;27(4):2727-2738

Neurofeedback

Used in clinical practice, aimed mostly at the increase of alpha rhythms for relaxation, sometimes combined with theta rhythms.

Critical review of existing literature shows that this is not effective.

New forms based on brain fingerprinting needed!



In search of the sources of brain's cognitive activity

Project „Symfonia”, NCN, Kraków, 18 July 2016

FACULTY OF PHYSICS, ASTRONOMY AND INFORMATICS

CENTRE FOR MODERN INTERDISCIPLINARY TECHNOLOGIES

INSTITUTE OF PHYSIOLOGY AND PATHOLOGY OF HEARING

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Conclusions

- We begin to understand the mappings between brain states and mental images – but it is still a tip of iceberg.
- Understanding neurodynamics and neurocognitive phenomics are the key to brain's self-regulation.
- Brain neuroimaging and computational simulations provide models of conscious information processing.
- Finding fingerprints of cognitive brain activity and understanding functional role of subnetworks will lead the way to **cognitive brain control methods** for restoration of functions through direct brain stimulation, neurofeedback, and neural grafting.
- Conscious control of brains will also be useful for healthy brains.

Pień Mózgu

Dariusz Mikołajewski

Włodzisław Duch

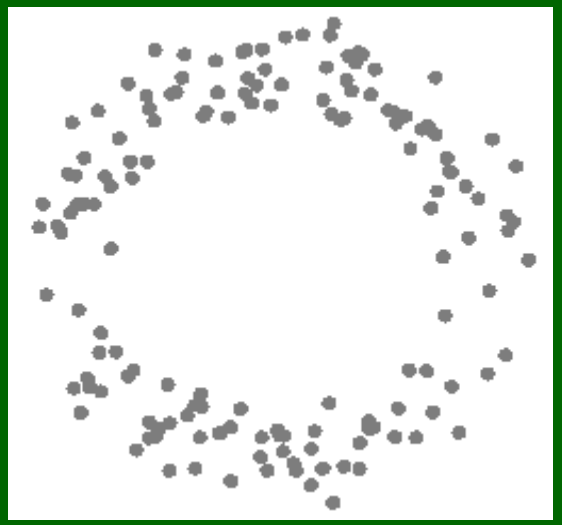
Pień mózgu

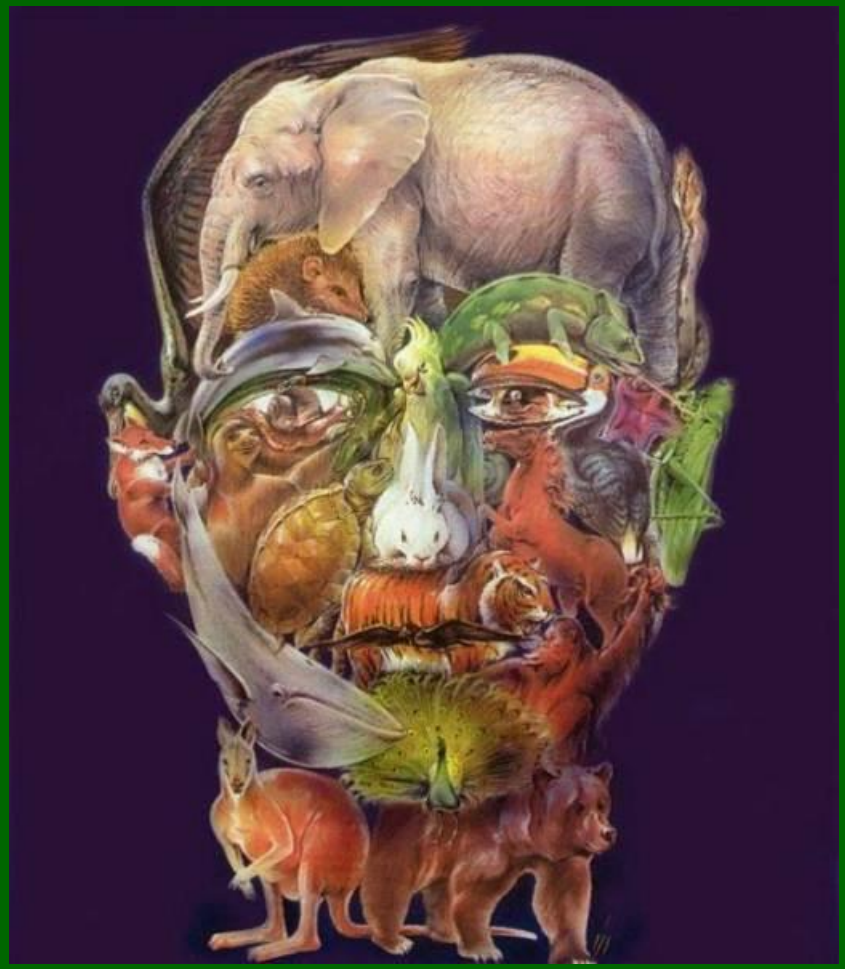
Przybliżenie aspektów medycznych

dzięki modelowaniu biocybernetycznemu

Wydawnictwo Naukowe UMK – właśnie dokonuje adjustacji 9/2017

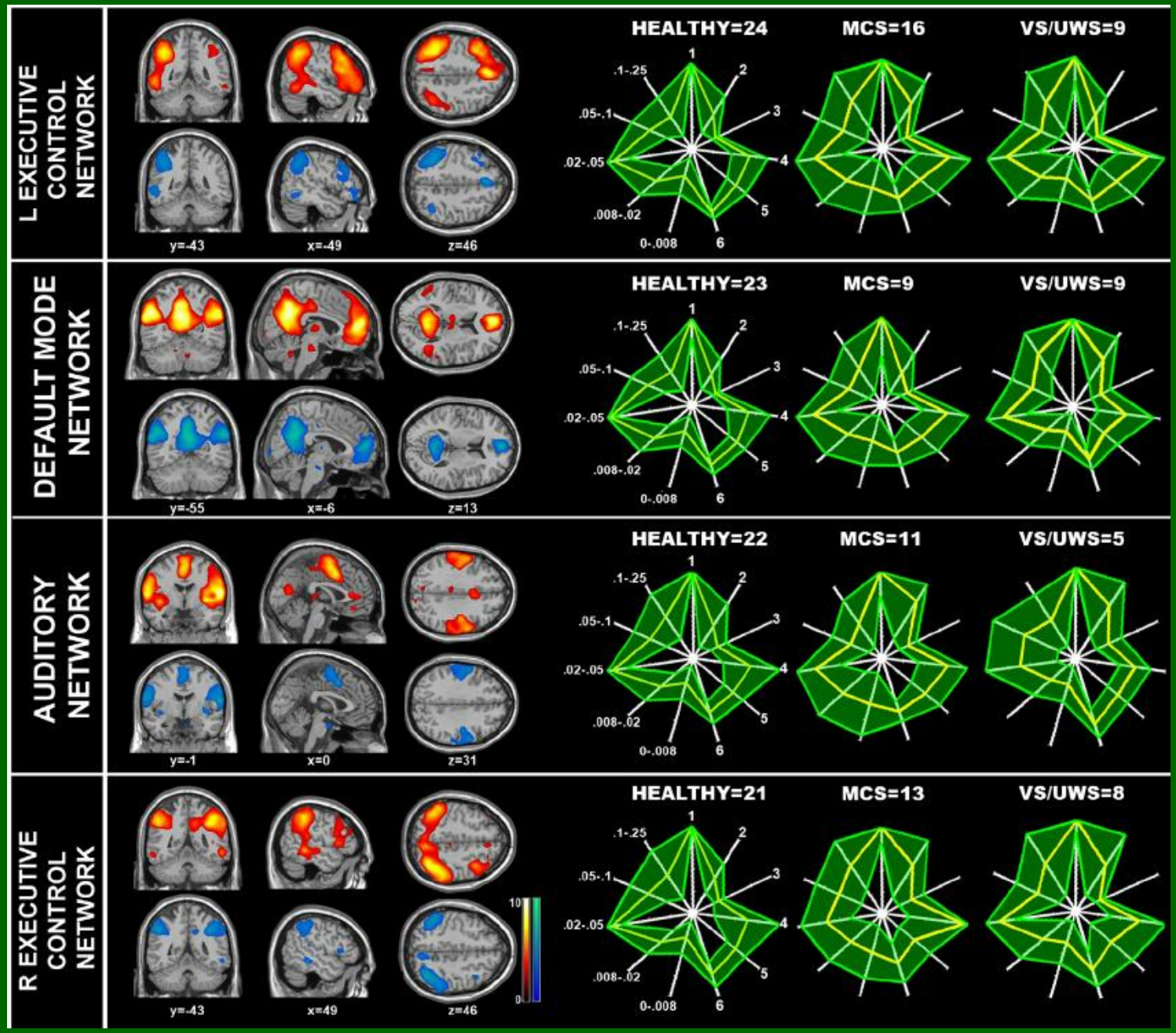
Thank for synchronization of your neurons



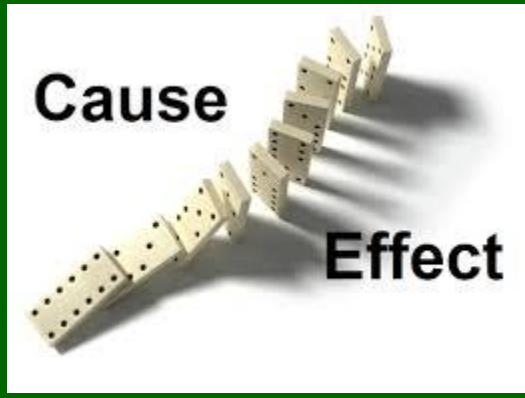


Google: W. Duch
=> talks, papers, lectures …

Demertzi, A. et al. (2014). Multiple fMRI system-level baseline connectivity is disrupted in patients with consciousness alterations. Cortex, 52, 35–46.



IIT postulates



The IIT is based on 5 general postulates, expressed in a rather abstract way below. They may be translated to properties of attractor networks in brain-inspired cognitive architectures.

1. **Intrinsic existence**: must have cause–effect power upon itself.
2. **Structured subsets** of the elementary mechanisms of the system, composed in various combinations, also have cause–effect power.
3. Information is in the cause–effect repertoires is specified by each composition of elements within a system.
4. **The cause–effect structure** specified by the system must be unified: it must be intrinsically irreducible, **a quale**.
5. The cause–effect structure specified by the system must be definite, specified over a single set of elements over which it is maximally irreducible from its intrinsic perspective.

IIT conclusions

Consciousness is a fundamental property of certain physical systems, like brains, having real cause–effect power, specifically the power of shaping the space of possible past and future states in a way that is maximally irreducible intrinsically (Φ measure).

Quantity (strength) and quality (shape) of experience is defined by the conceptual structure that is maximally irreducible intrinsically: quality differs depending on configuration of elements involved.

Feedforward systems cannot be conscious, recurrence is needed.

Computer simulation of the brain are virtual and will not create consciousness - physical activity of computer elements is not sufficiently integrated in a unified process, breaks down into many mini-complexes of low Φ^{max}.

However, Tononi and Koch do not mention neurocomputers based on massively parallel neurochips (as for ex. in the SYNAPSE project). According to IIT such systems could become conscious and it can be measured.