Optimizing brain processes. Neurocognitive technologies.

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Google: W. Duch

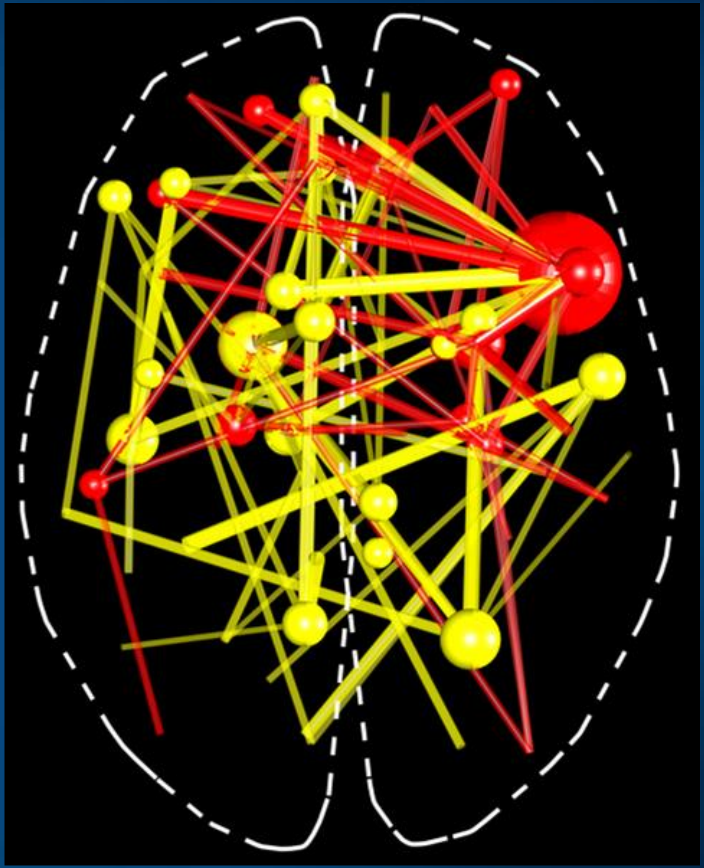
2018.05.16: Surrey University

On the threshold of a dream …

Optimization of brain processes?

How can we interpret/use brain signals?

- Brain ⇔ Mind relations.
- Brain networks. Space for neurodynamics.
- Fingerprints of Mental Activity.
- Dynamic functional brain networks.
- Human Enhancement
- Optimization of brain processes
- Neurocognitive technologies.



Duch W (1996) *Computational physics of the mind*.
Computer Physics Communication **97**: 136-153

My NeuroCog projects

Neurocognitive Informatics: understanding complex cognition => creating algorithms that work in similar way.

- Computational creativity, insight, intuition, imagery.
- Geometric theory of brain-mind processes.
- Imagery agnosia, amusia, musical talent, learning preferences.
- Infants: observation, perception/WM development.
- Neurocognitive approach to language, word games.
- Brain stem models & consciousness in artificial systems.
- **Comprehensive theory of autism** and ADHD, phenomics.
- Medical information retrieval, analysis, visualization.
- Understanding neurodynamics, EEG signals, neurofeedback.
- Philosophy: neural determinism, free will & social consequences.

ML: see A few machine learning algorithms worth further development.
Many good unfinished -;) ideas in Machine Learning.
INCF Poland node in Toruń (2017).

My group of neuro-cog-fanatics

CMIT: scanner GE Discovery MR750 3T

In search of the sources of brain's cognitive activity

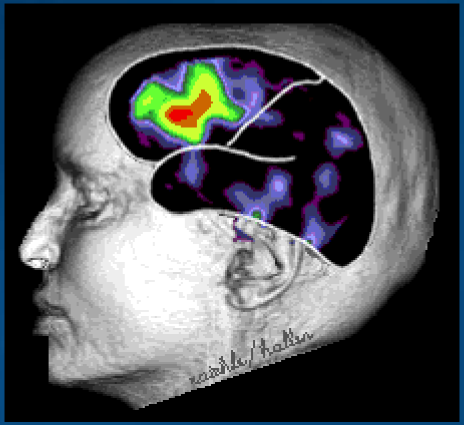
Project „Symfonia”, NCN, Kraków, 18 July 2016

Looking for a postdock (5/2018)!

FACULTY OF PHYSICS, ASTRONOMY AND INFORMATICS
CENTRE FOR MODERN INTERDISCIPLINARY TECHNOLOGIES
INSTITUTE OF PHYSIOLOGY AND PATHOLOGY OF HEARING
nencki institute of experimental biology

Two worlds

Neurodynamics: bioelectrical activity of the brain, neural activity measured using EEG, MEG, NIRS-OT, PET, fMRI, other techniques.



Mapping:
State(Brain)⇔State(Mind)
via intermediate BCI models.

Mental states, movement of thoughts ⇔ trajectories in psychological spaces.

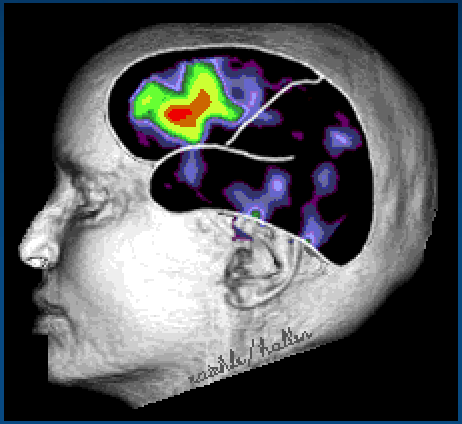
1. From simulations and neuroimaging to mental trajectories.
2. From neuroimaging to mental images.

Teaching: **Przetwarzanie informacji przez mózgi**, monograph in cognitive science (2002) at NCU.

Geometric model of mind

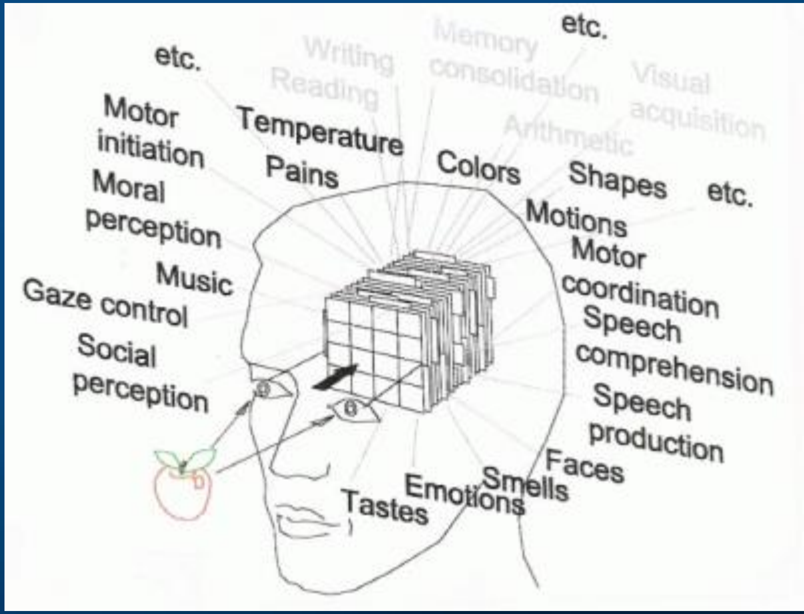
Brain ⇔ Psyche

Objective ⇔ Subjective



Neurodynamics: bioelectrical activity of the brain, neural activity measured using EEG, MEG, NIRS-OT, PET, fMRI, other techniques.

Mapping S(M)⇔S(B) but how do we describe the state of mind?



Verbal description is not sufficient.
A space with dimensions that measure different aspects of experience is needed.

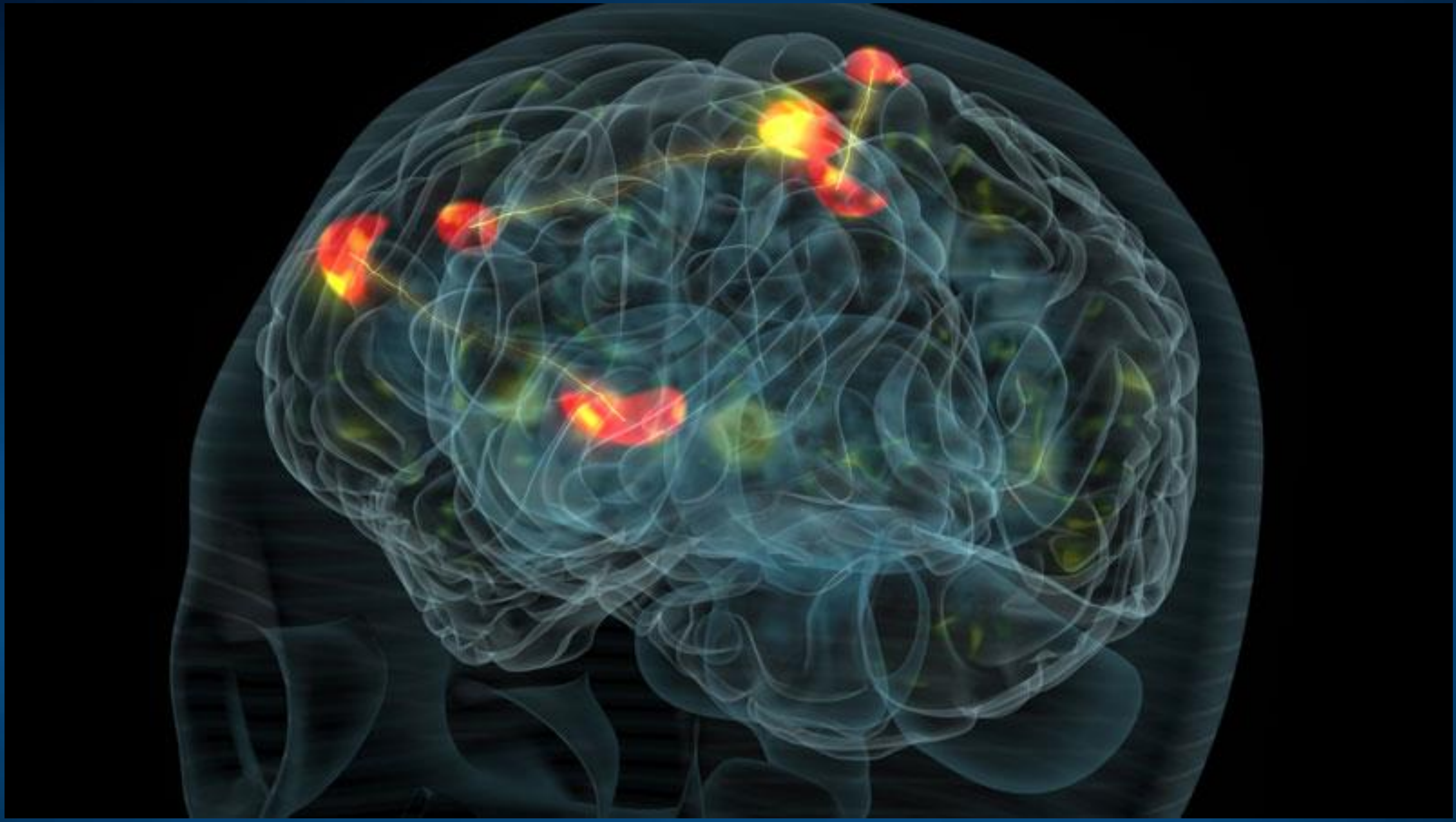
Mental states, movement of thoughts ⇔ trajectories in psychological spaces.

Problem: good phenomenology. We are not able to describe our mental states.

Hurlburt & Schwitzgabel, Describing Inner Experience? MIT Press 2007

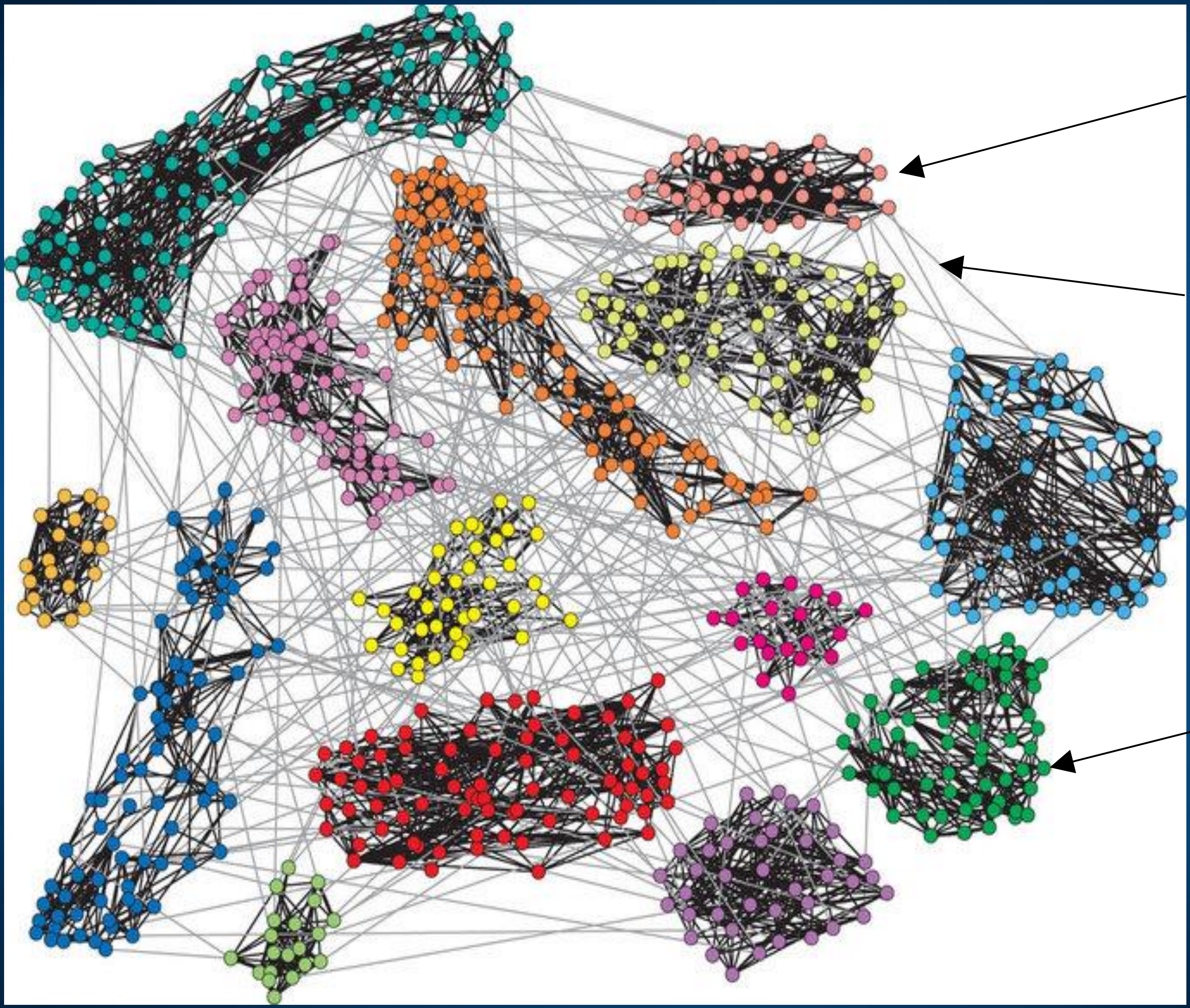
Brain networks.
Space for neurodynamics.

Mental state: strong coherent activation

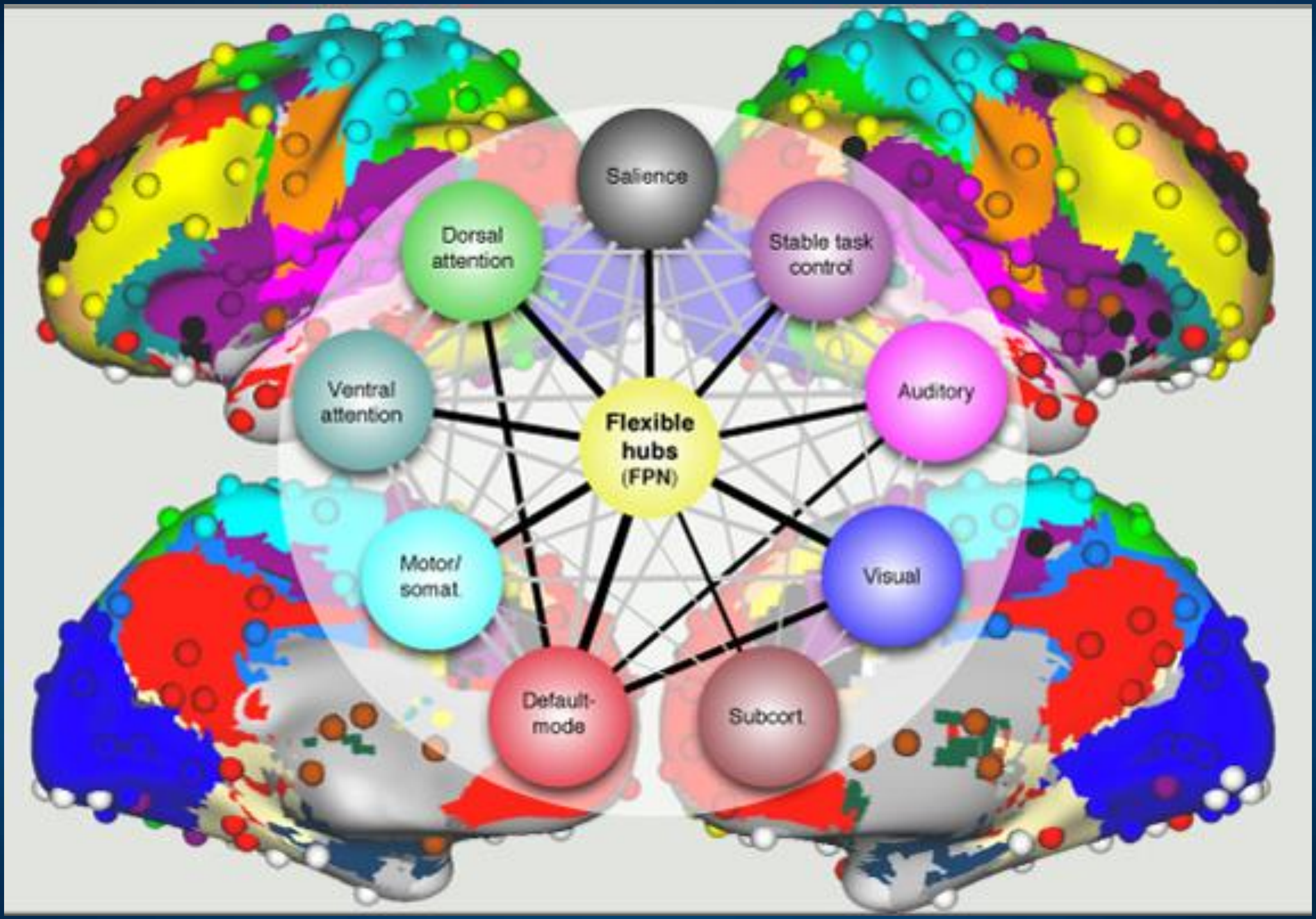


Many processes go on in parallel, controlling homeostasis and behavior. Most are automatic, hidden from our Self. What goes on in my head? Various subnetworks compete for access to the highest level of control - consciousness, the winner-takes-most mechanism leaves only the strongest. How to extract stable intentions from such chaos? BCI is never easy.

Brain networks: canvas for the mind

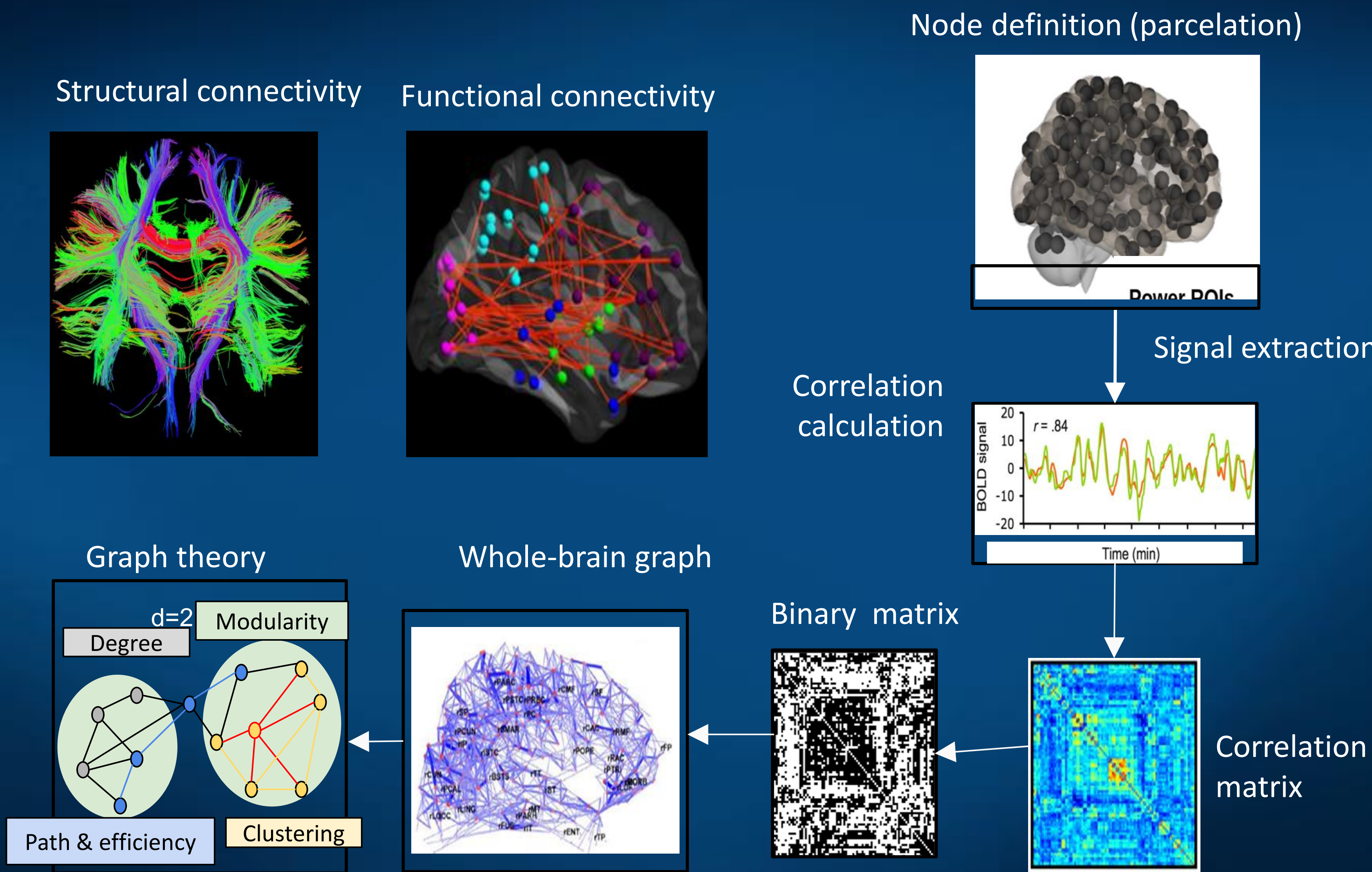


Neurocognitive Basis of Cognitive Control



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

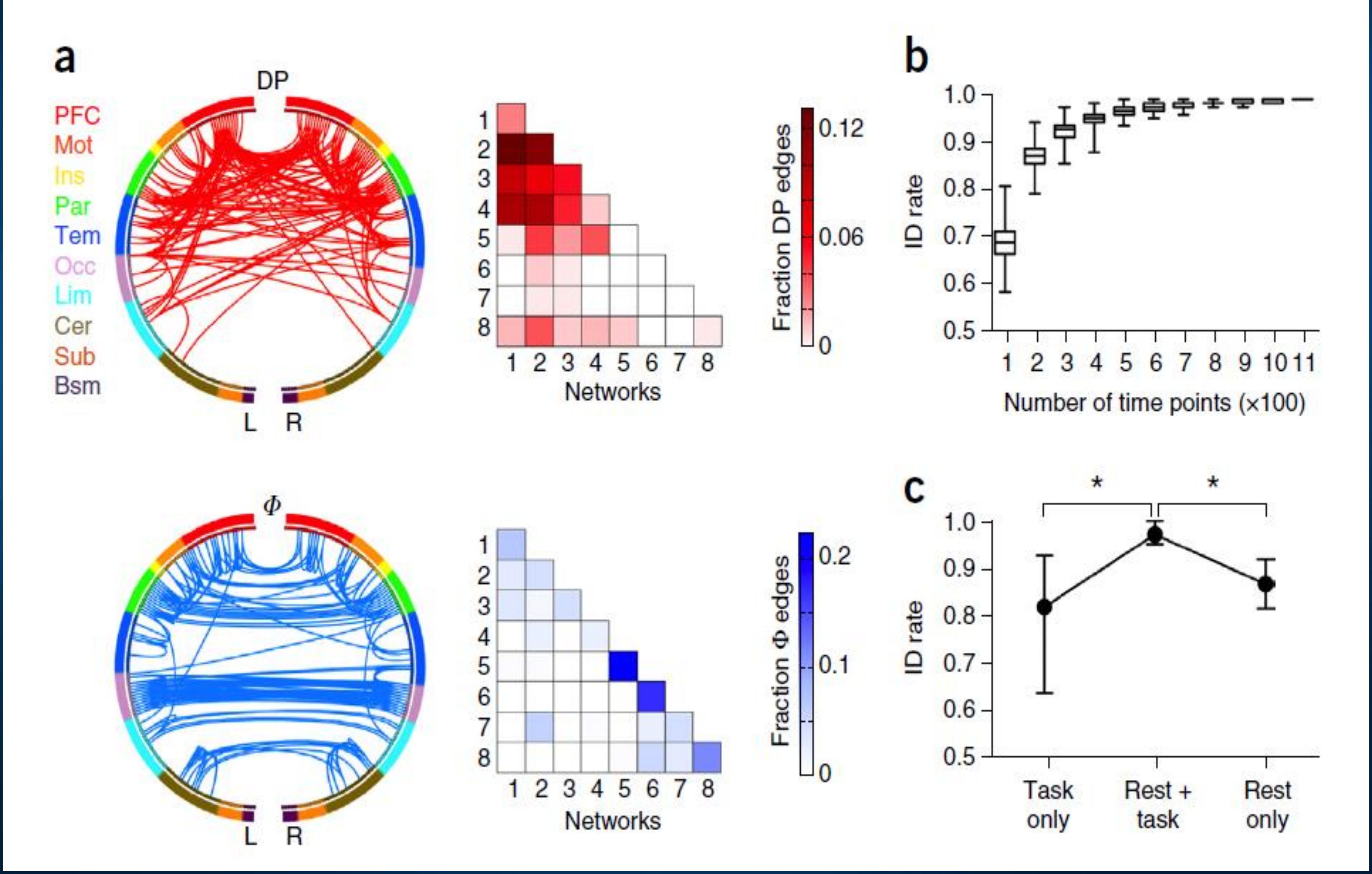
Human connectome and MRI/fMRI



Many toolboxes available for such analysis.

Bullmore & Sporns (2009)

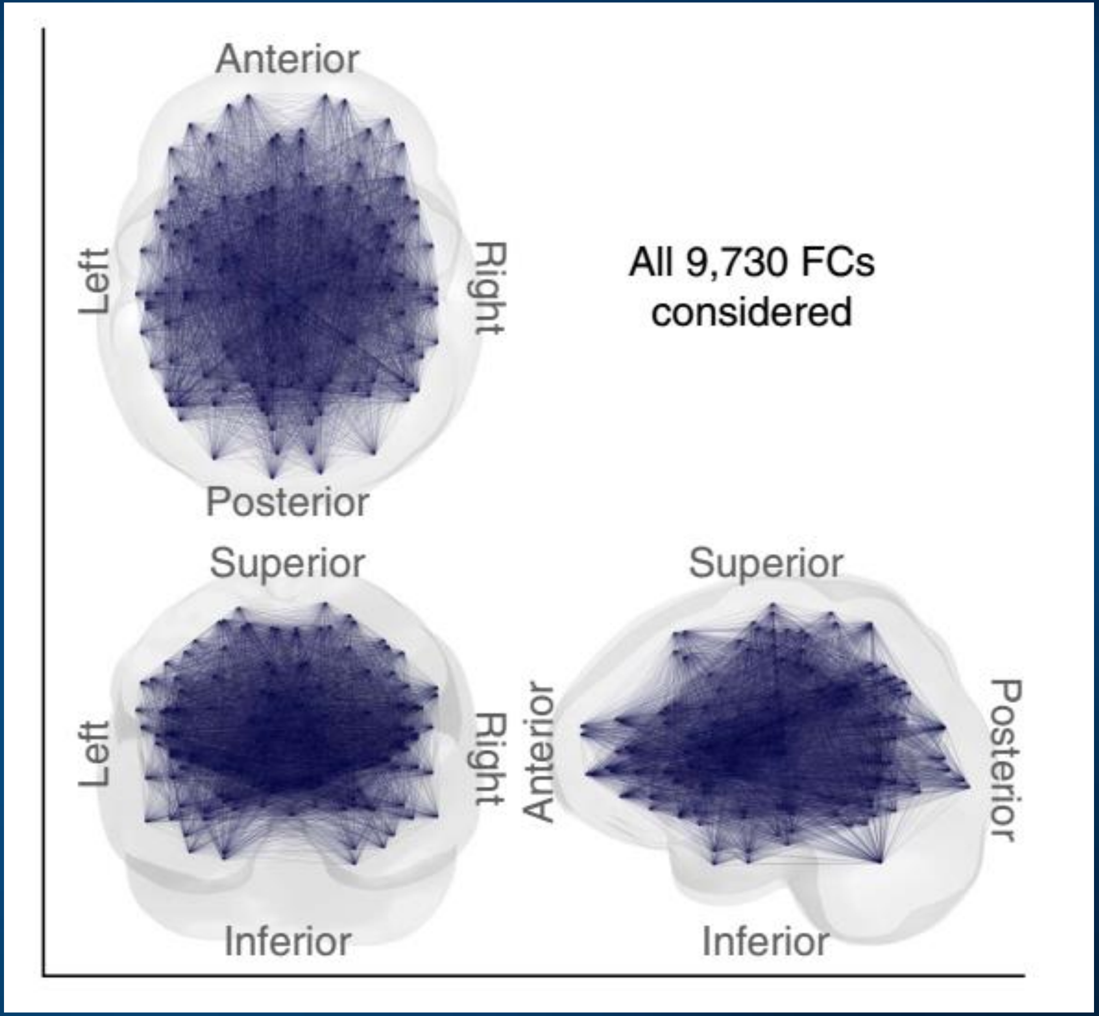
Finn et al. (2015), **Functional connectome fingerprinting**: identifying individuals using patterns of brain connectivity. Nature Neuroscience. Top: highly unique; Bottom: highly consistent connections.



ASD connectome

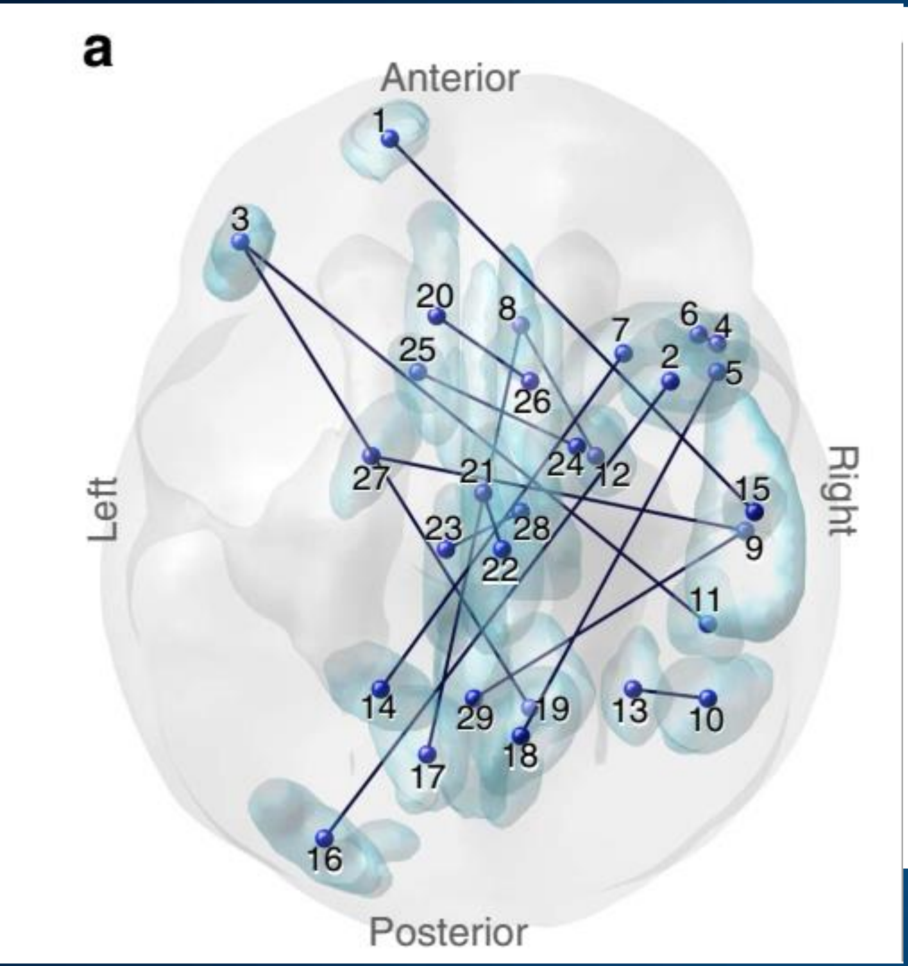
Analysis of functional connections (using Brain Connectivity Toolbox) between brain regions measured using fMRI in the resting state between 140 ROIs leads to 9730 possible functional interactions (direction not distinguished).

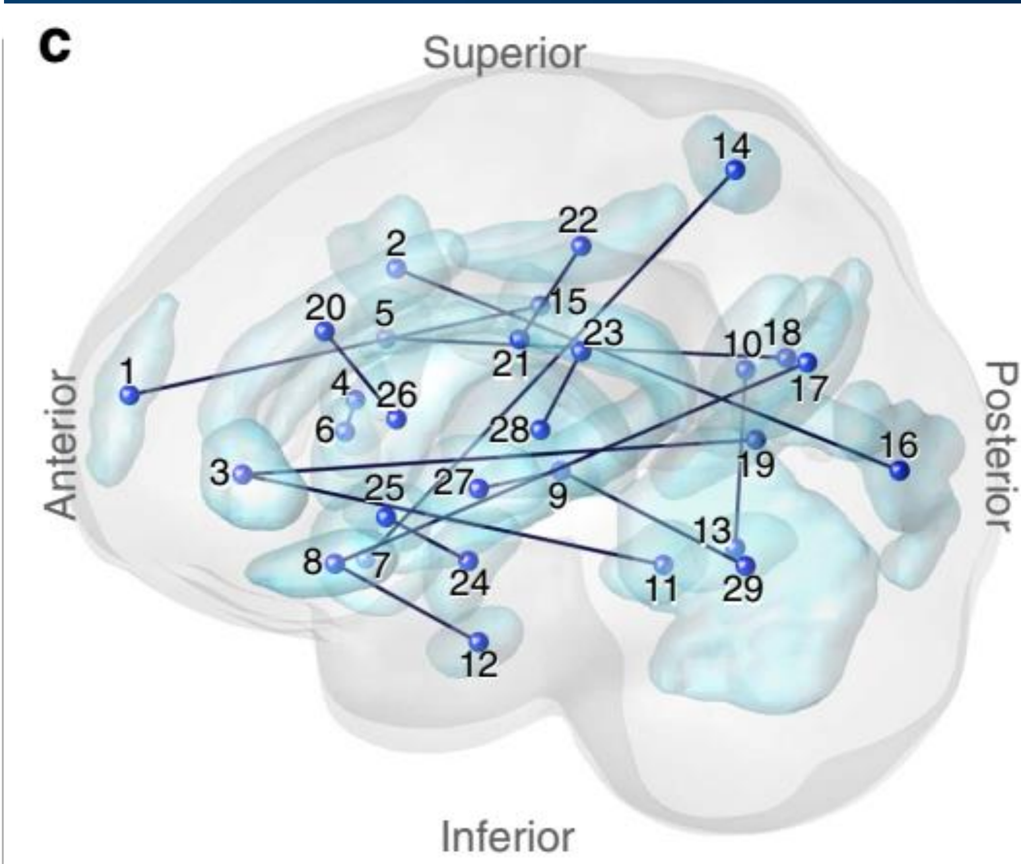
Selecting the most important 16 connections classification accuracy of 85% was reached, distinguishing ASD people form the healthy ones.



N. Yahata et al., A small number of abnormal brain connections predicts adult autism spectrum disorder. Nature Communications (2016)

Selected connections





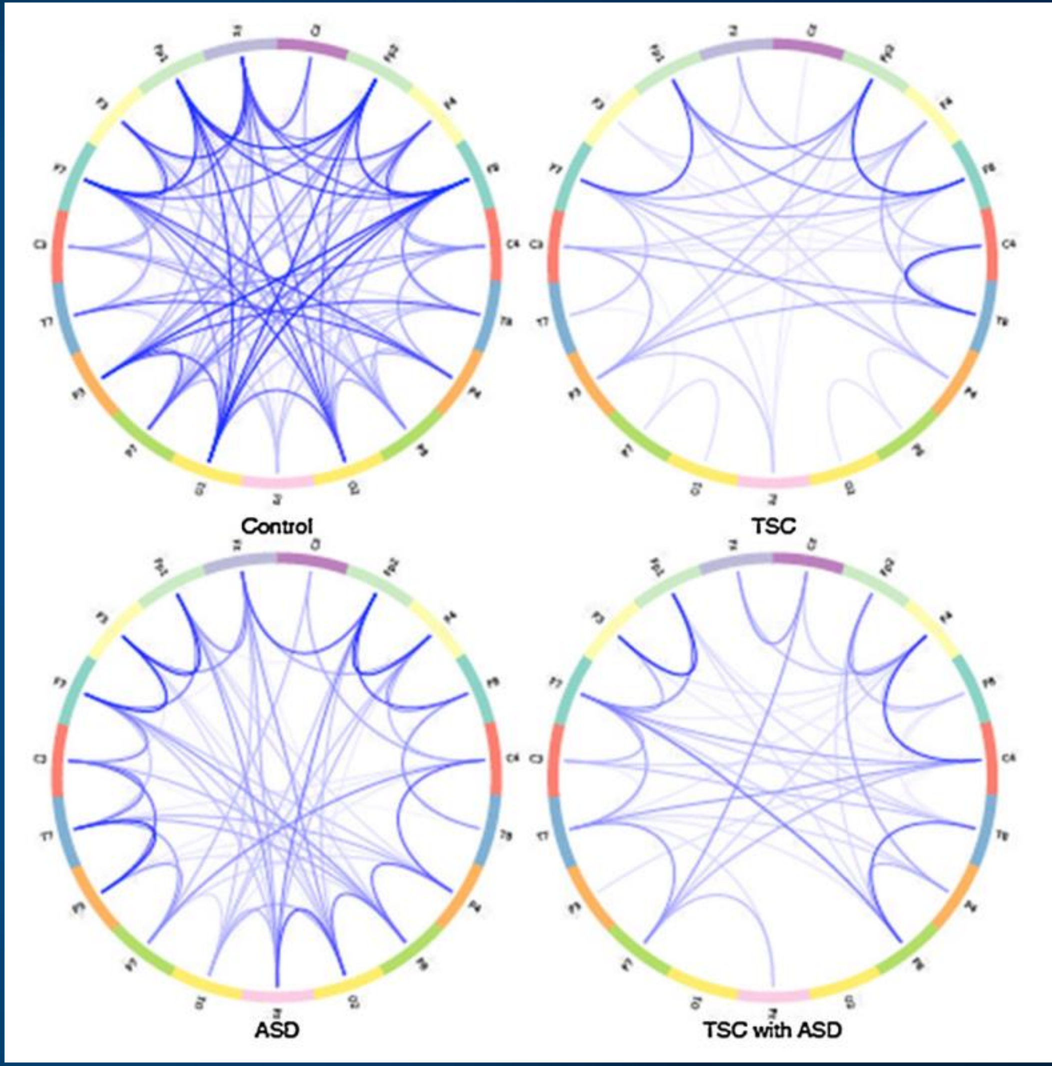
N. Yahata et al, 29 selected regions (ROI) and 16 connections were sufficient to recognize ASD with 85% accuracy in 74 Japanese adult patients vs. 107 people in control group; without re-training accuracy was 75% on US patients. Movie.

ASD: pathological connections

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

Coherence between electrodes. 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; **correct your networks**!



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

NIMH RDoC Matrix for deregulation of large brain systems.

Instead of classification of mental disease by symptoms use **Research Domain Criteria** (RDoC) based on **multi-level neuropsychiatric phenomics**.

1. **Negative Valence Systems**, primarily responsible for responses to aversive situations or context, such as fear, anxiety, and loss.
2. **Positive Valence Systems** are primarily responsible for responses to positive motivational situations or contexts, such as reward seeking, consummatory behavior, and reward/habit learning.
3. **Cognitive Systems** are responsible for various cognitive processes.
4. **Social Processes Systems** mediate responses in interpersonal settings of various types, including perception and interpretation of others' actions.
5. **Arousal/Regulatory Systems** are responsible for generating activation of neural systems as appropriate for various contexts, providing appropriate homeostatic regulation of such systems as energy balance and sleep.

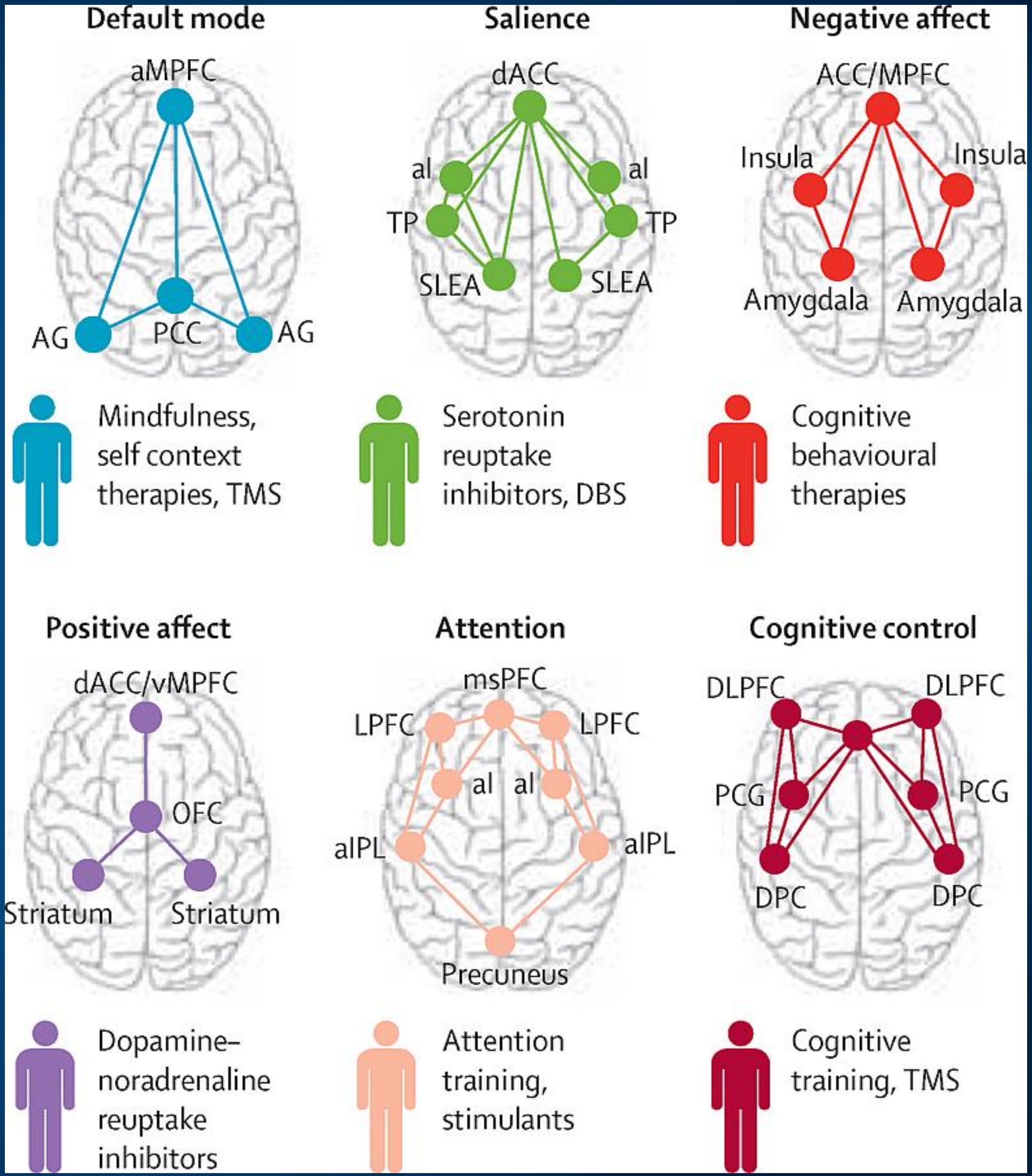
RDoC Matrix for „cognitive domain”

Construct/Subconstruct		Genes	Molecules	Cells	Circuits	Physiology	Behavior	Self-Report	Paradigms
Attention		Elements	Elements	Elements	Elements	Elements	Elements		Elements
Perception	Visual Perception	Elements	Elements	Elements	Elements	Elements	Elements	Elements	Elements
	Auditory Perception	Elements	Elements	Elements	Elements	Elements	Elements	Elements	Elements
	Olfactory/Somatosensory/Multimodal/Perception								Elements
Declarative Memory		Elements	Elements	Elements	Elements	Elements	Elements	Elements	Elements
Language		Elements			Elements	Elements	Elements	Elements	Elements
Cognitive Control	Goal Selection; Updating, Representation, and Maintenance ⇒ Focus 1 of 2 ⇒ Goal Selection				Elements			Elements	Elements
	Goal Selection; Updating, Representation, and Maintenance ⇒ Focus 2 of 2 ⇒ Updating, Representation, and Maintenance	Elements	Elements	Elements	Elements	Elements	Elements	Elements	Elements
	Response Selection; Inhibition/Suppression ⇒ Focus 1 of 2 ⇒ Response Selection	Elements	Elements	Elements	Elements	Elements	Elements	Elements	Elements
	Response Selection; Inhibition/Suppression ⇒ Focus 2 of 2 ⇒ Inhibition/Suppression	Elements	Elements	Elements	Elements	Elements	Elements	Elements	Elements
	Performance Monitoring	Elements	Elements		Elements	Elements	Elements	Elements	Elements
Working Memory	Active Maintenance	Elements	Elements	Elements	Elements	Elements			Elements
	Flexible Updating	Elements	Elements	Elements	Elements	Elements			Elements
	Limited Capacity	Elements	Elements		Elements	Elements			Elements
	Interference Control	Elements	Elements	Elements	Elements	Elements			Elements

RDoC networks

aMPFC=anterior medial PFC
AG=angular gyrus. PCC=posterior cingulate cortex; dACC=dorsal anterior CC; aI=anterior insula.
TP=temporal pole.
SLEA=sublenticular extended amygdala.
LPFC=lateral PFC, M=medial
v=ventral, ms=medial superior,
vM =ventromedial,
aIPL=anterior inferior parietal lobule.

OFC=orbitofrontal cortex.
ACC=anterior cingulate cortex.
DLPFC=dorsolateral
PCG=precentral gyrus.
DPC=dorsal parietal cortex.

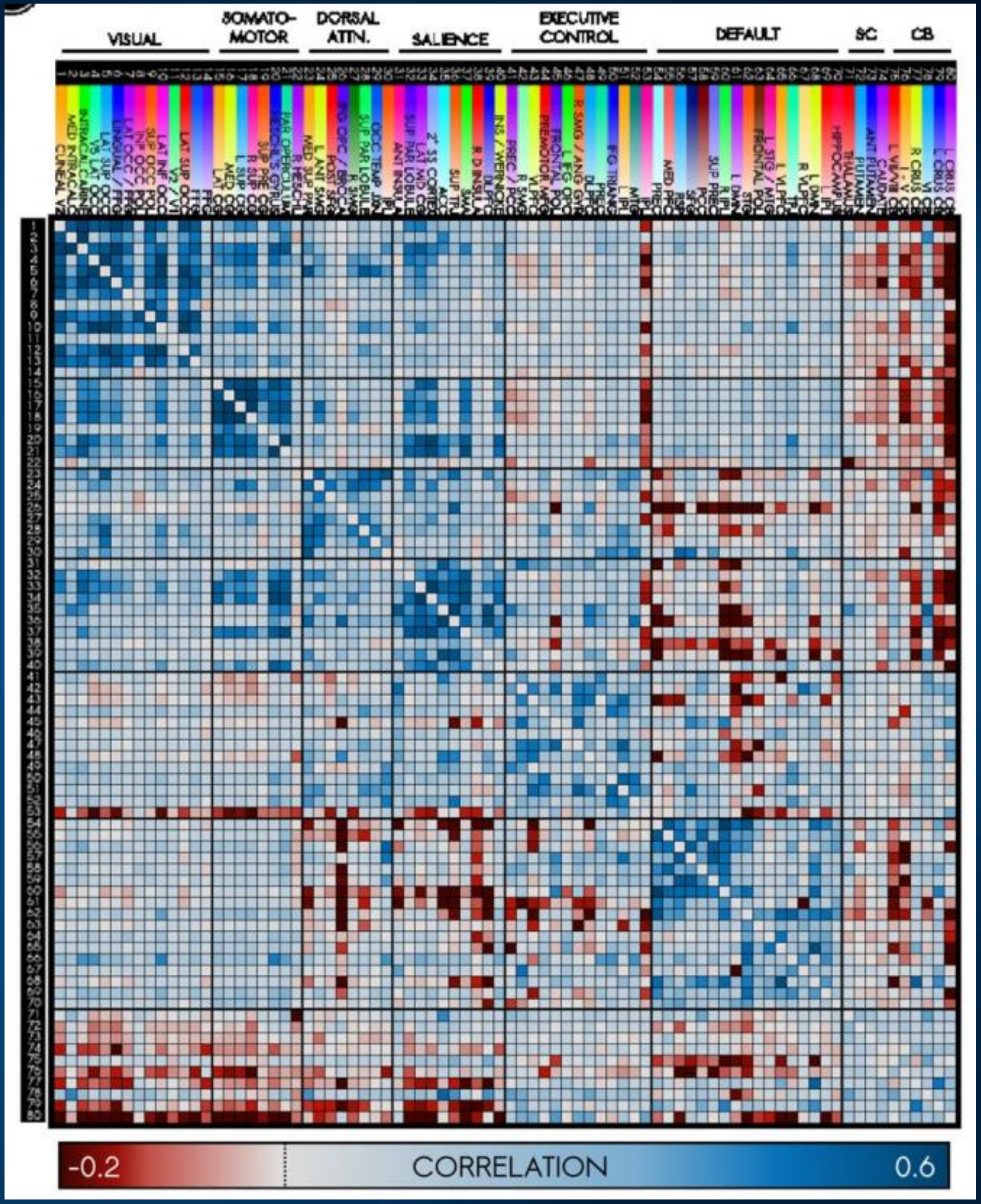


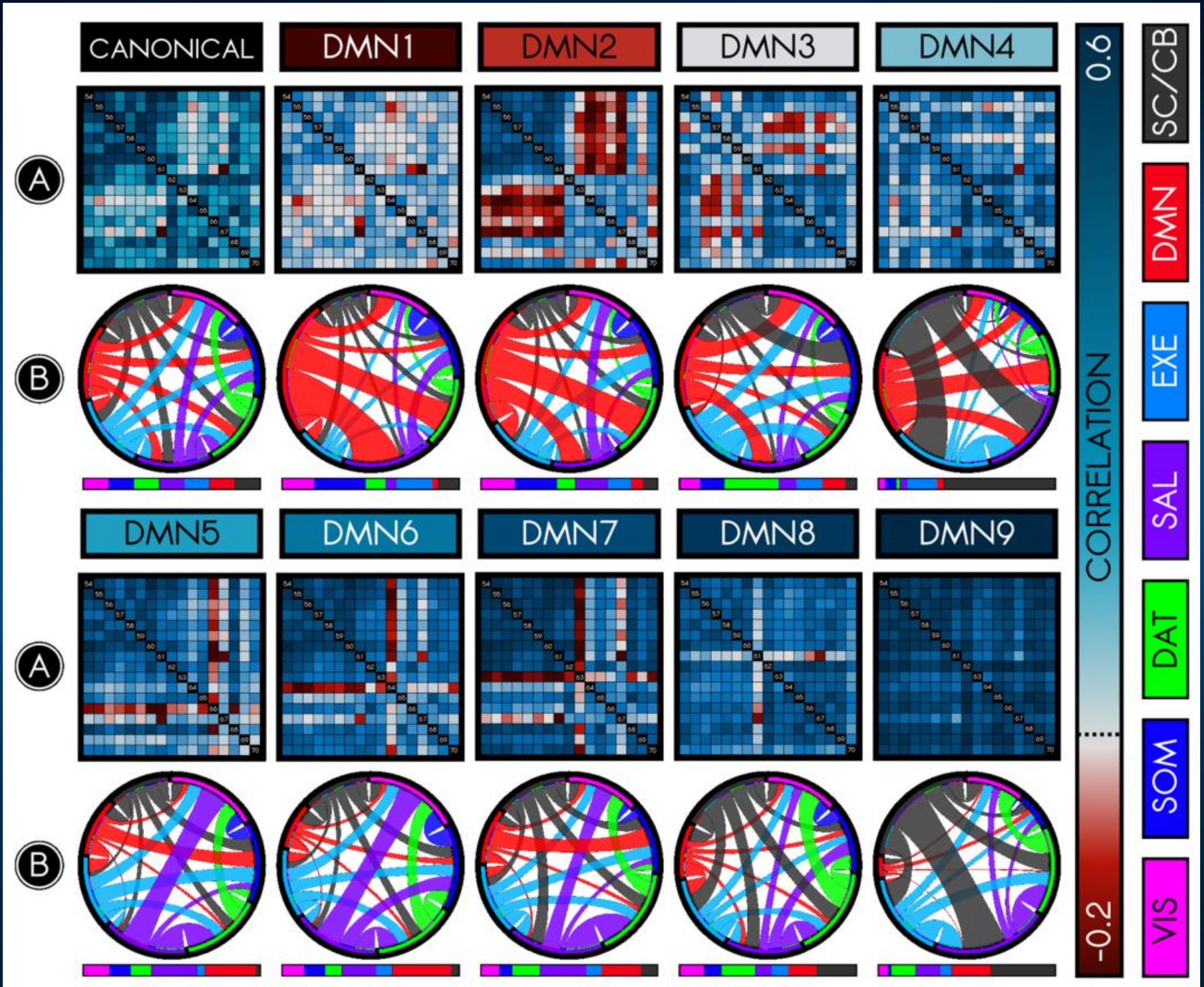
Correlations of 6 canonical networks.

Perception,
Action-attention
DMN (Default Mode Network)

Each has up to 10 different network connectivity states (NC-states), rather stable for single subjects, ex. DMN has usually 7-9.

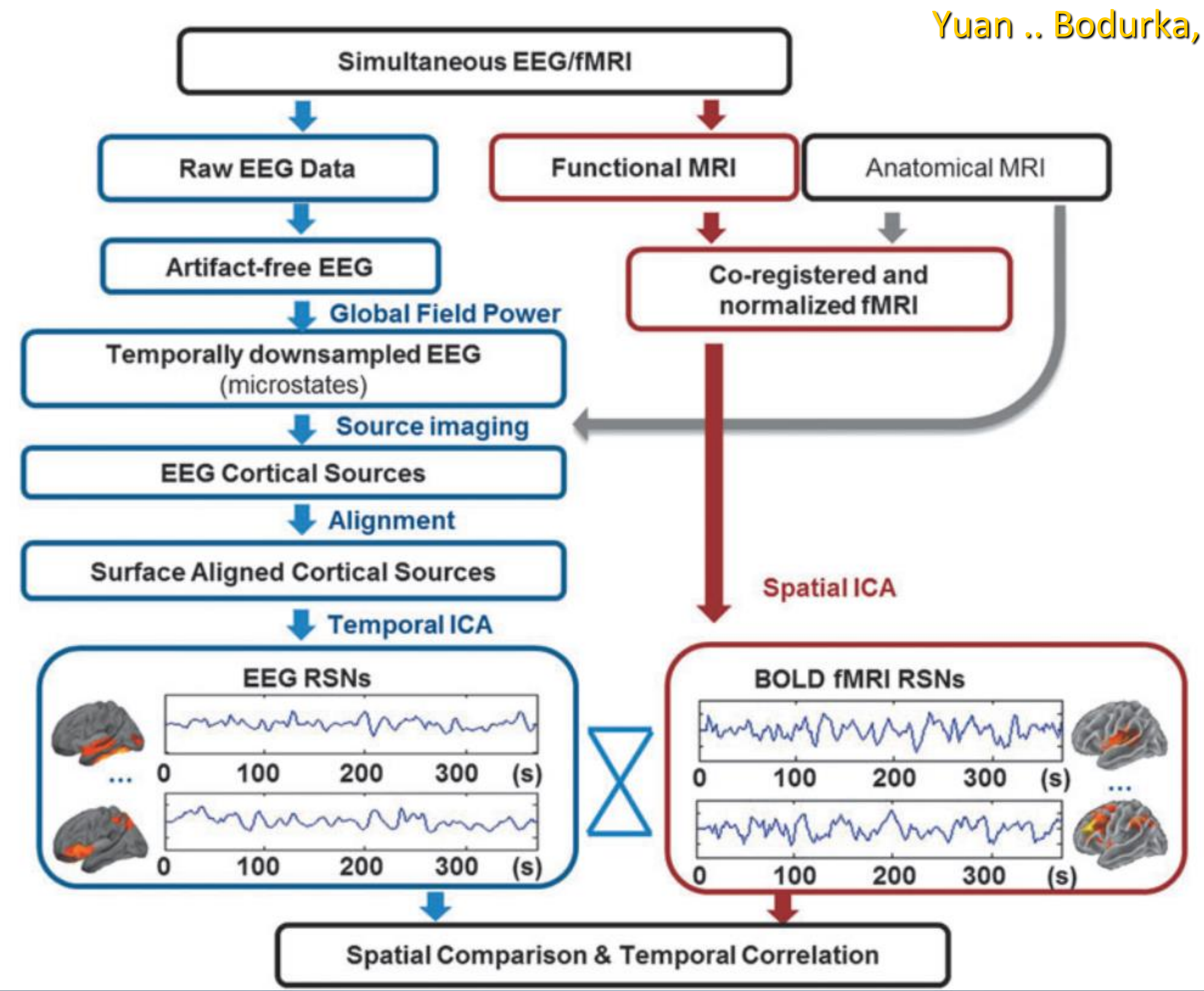
Ciric et.al. (2017). Contextual connectivity: A framework for understanding the intrinsic dynamic architecture of large-scale functional brain networks. *Scientific Reports*.



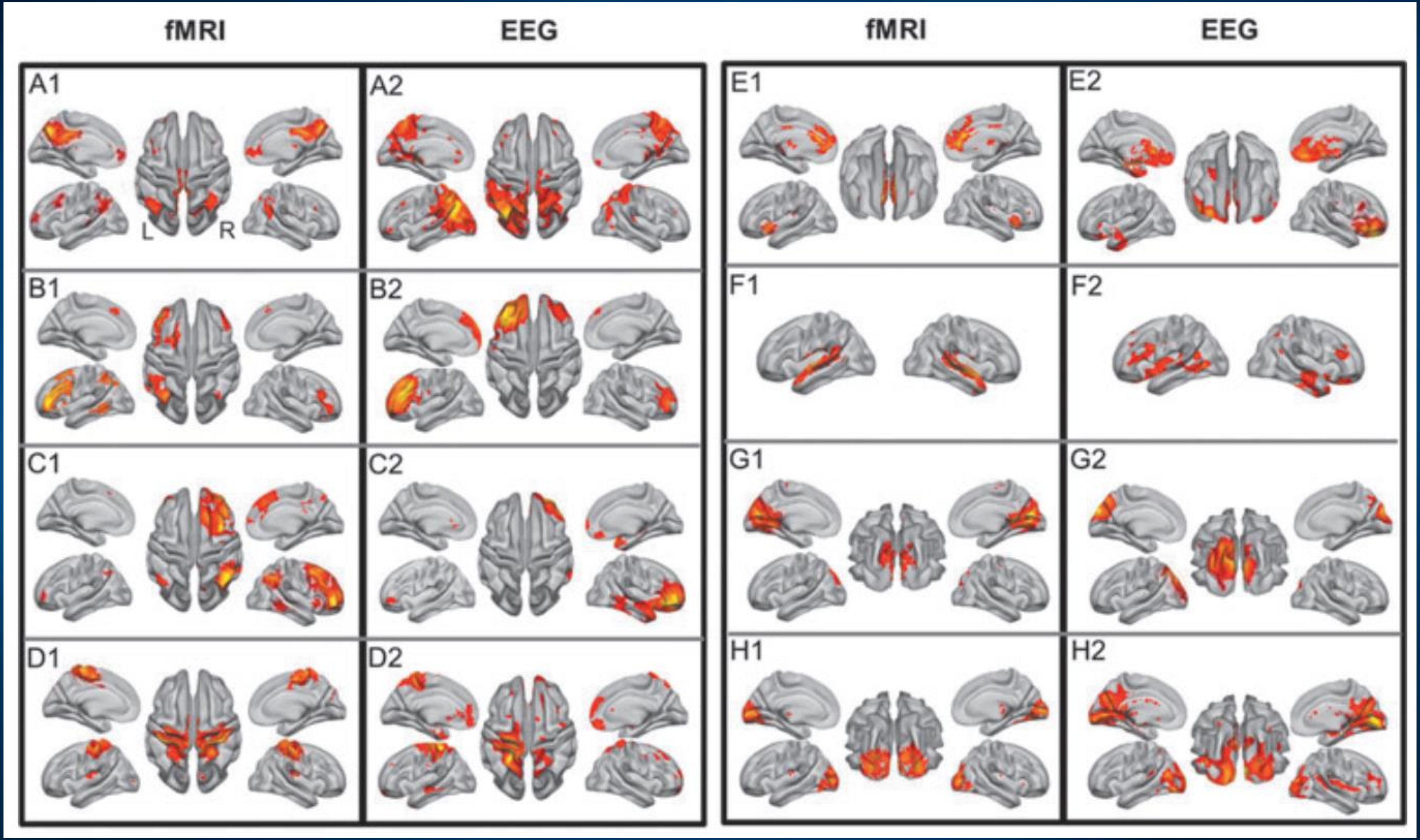


CANONICAL
DMN1
DMN2
DMN3
DMN4
DMN5
DMN6
DMN7
DMN8
DMN9
A
B
CORRELATION
0.6
-0.2
SC/CB
DMN
EXE
SAL
DAT
SOM
VIS

Yuan .. Bodurka, 2015

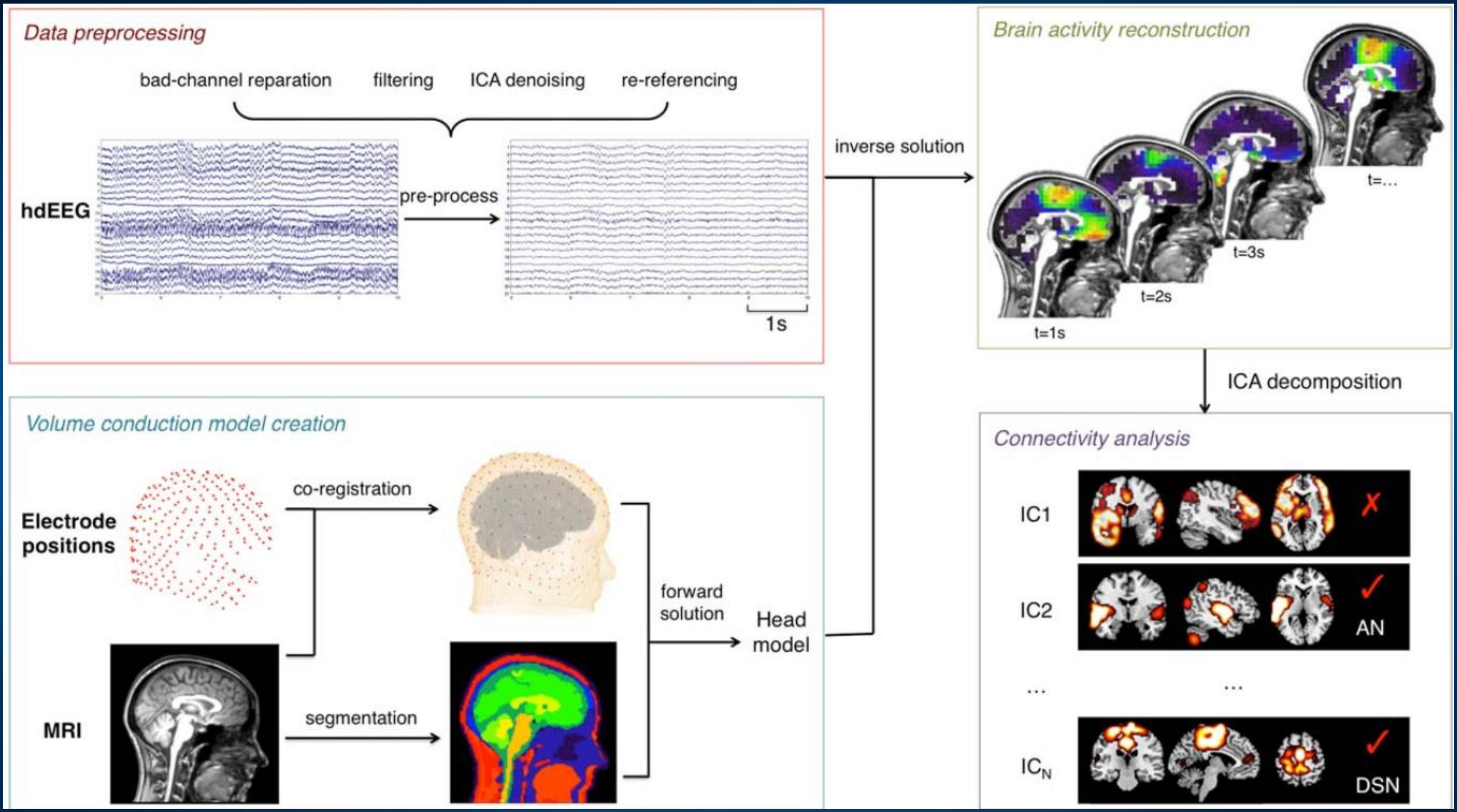


8 areas from BOLD-EEG



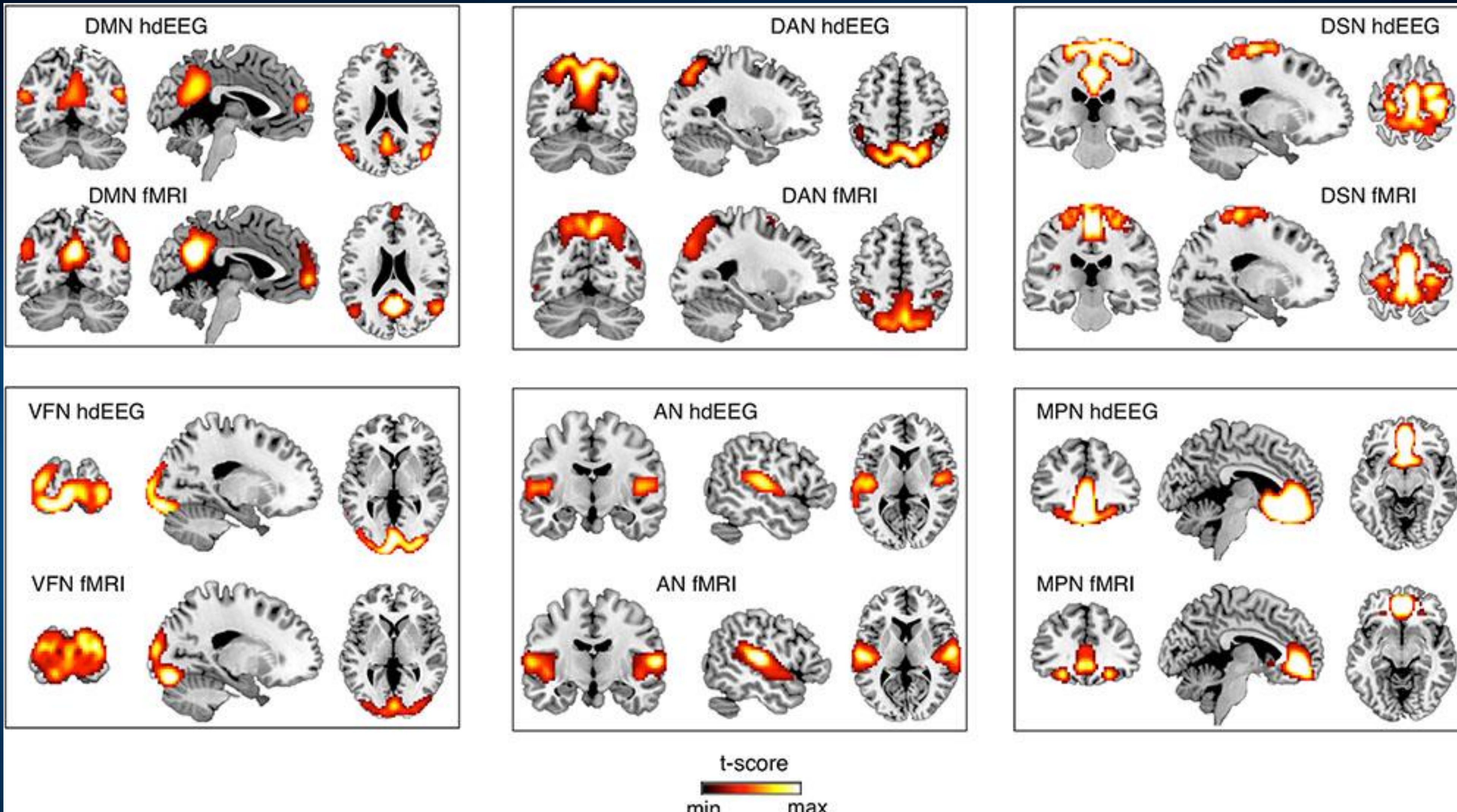
DMN, FP (frontoparietal)-left, right, sensorimotor, ex, control, auditory, visual (medial), (H) visual (lateral).   Yuan … Bodurka (2015)

14 networks from BOLD-EEG



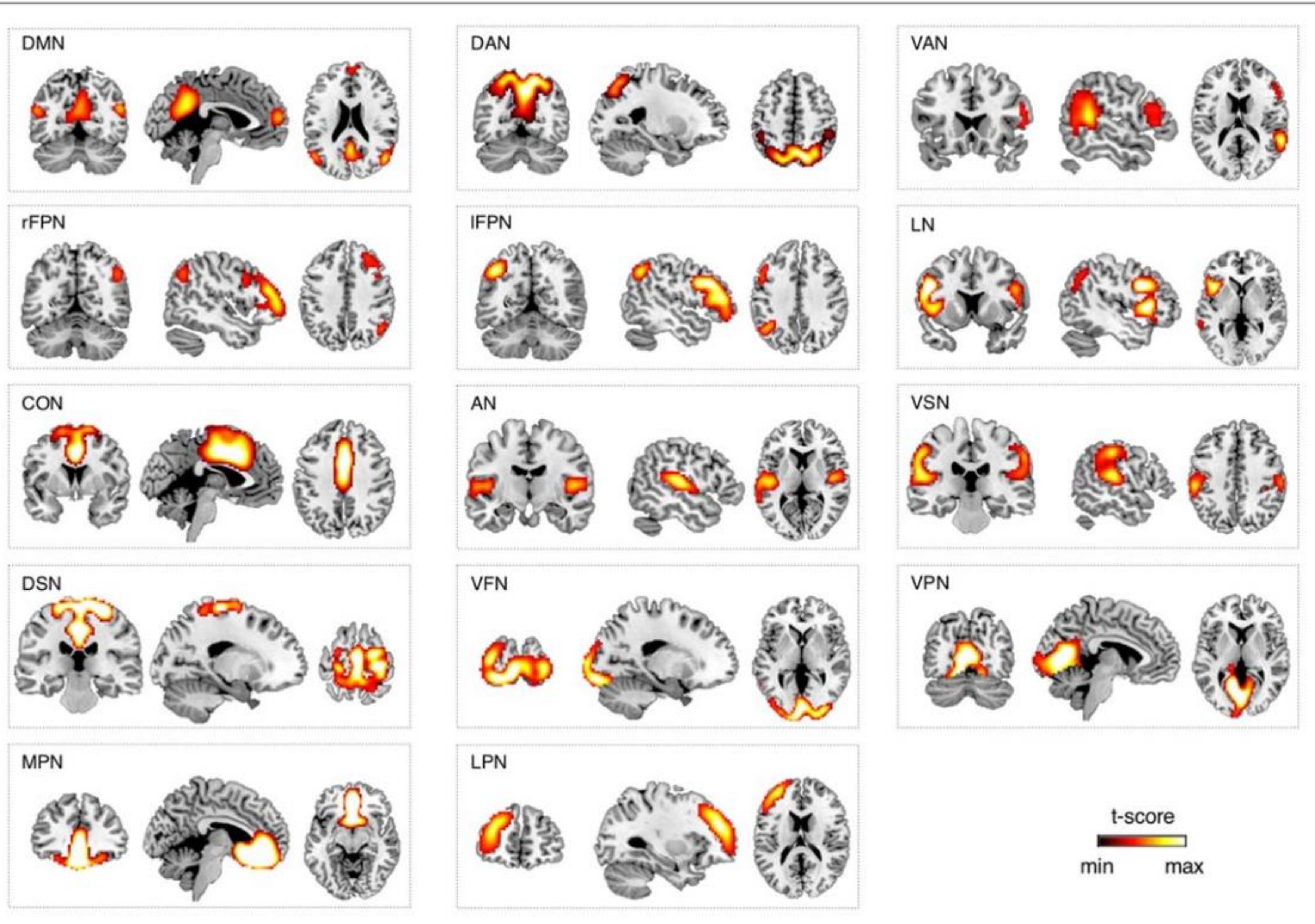
DMN, FP (frontoparietal)-left, right, sensorimotor, ex, control, auditory, visual (medial), (H) visual (lateral).

Liu et al. Detecting large-scale networks in the human brain. HBM (2017; 2018).



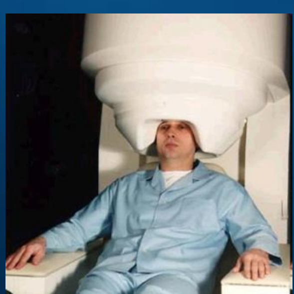
sICA on 10-min fMRI data ($N = 24$, threshold: $p < 0.01$, TFCE corrected). DMN, default mode network; DAN, dorsal attention network; DSN, dorsal somatomotor network; VFN, visual foveal network; AN, auditory network; MPN, medial prefrontal network.

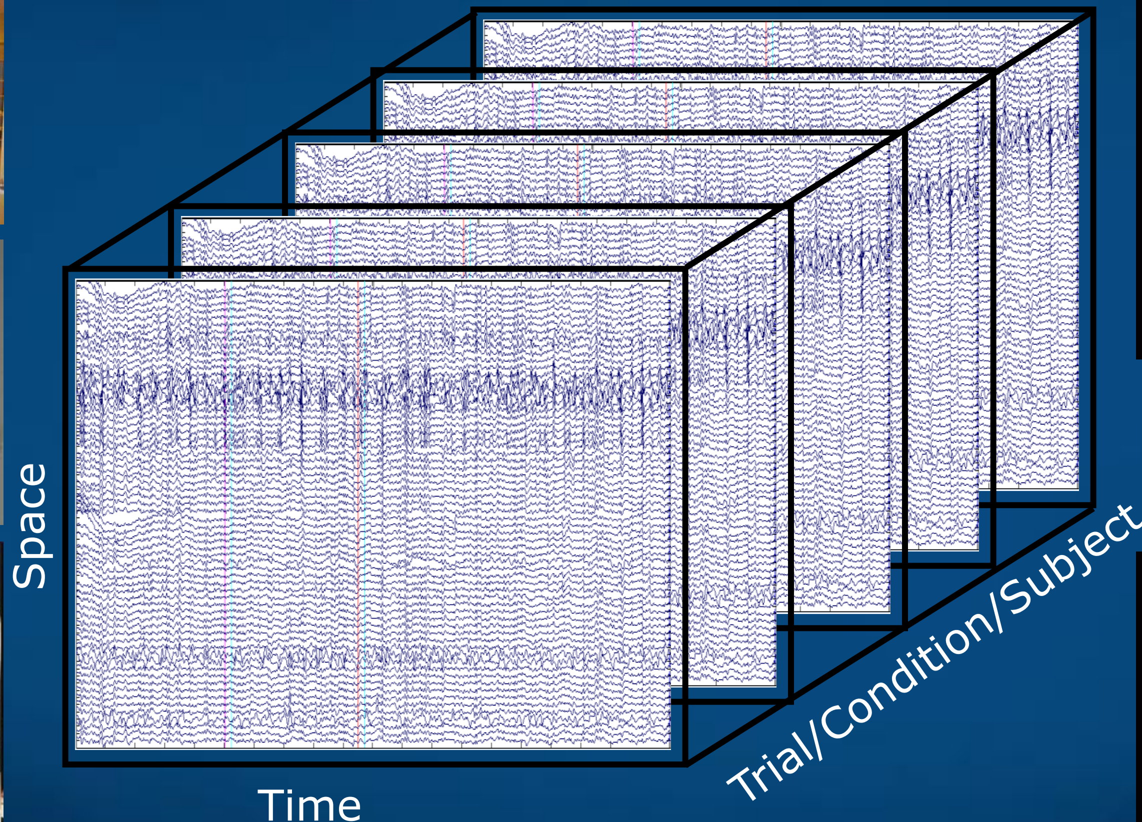
EEG-RSN maps obtained using spatial ICA

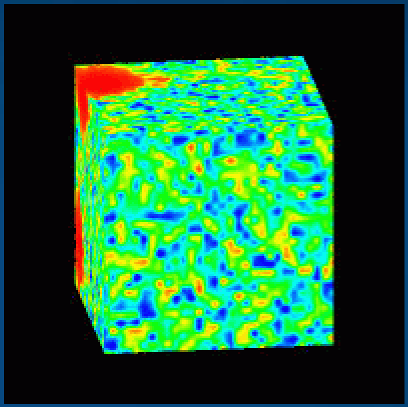


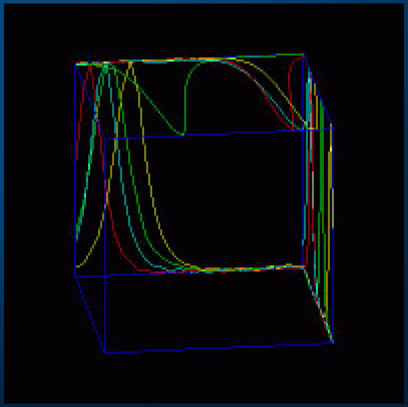
From Two-way to Multi-way Analysis
Integration and Fusion of Various Modalites
EEG+fNIRS +fMRI

A. Cichocki Lab
RIKEN Brain Science Inst.



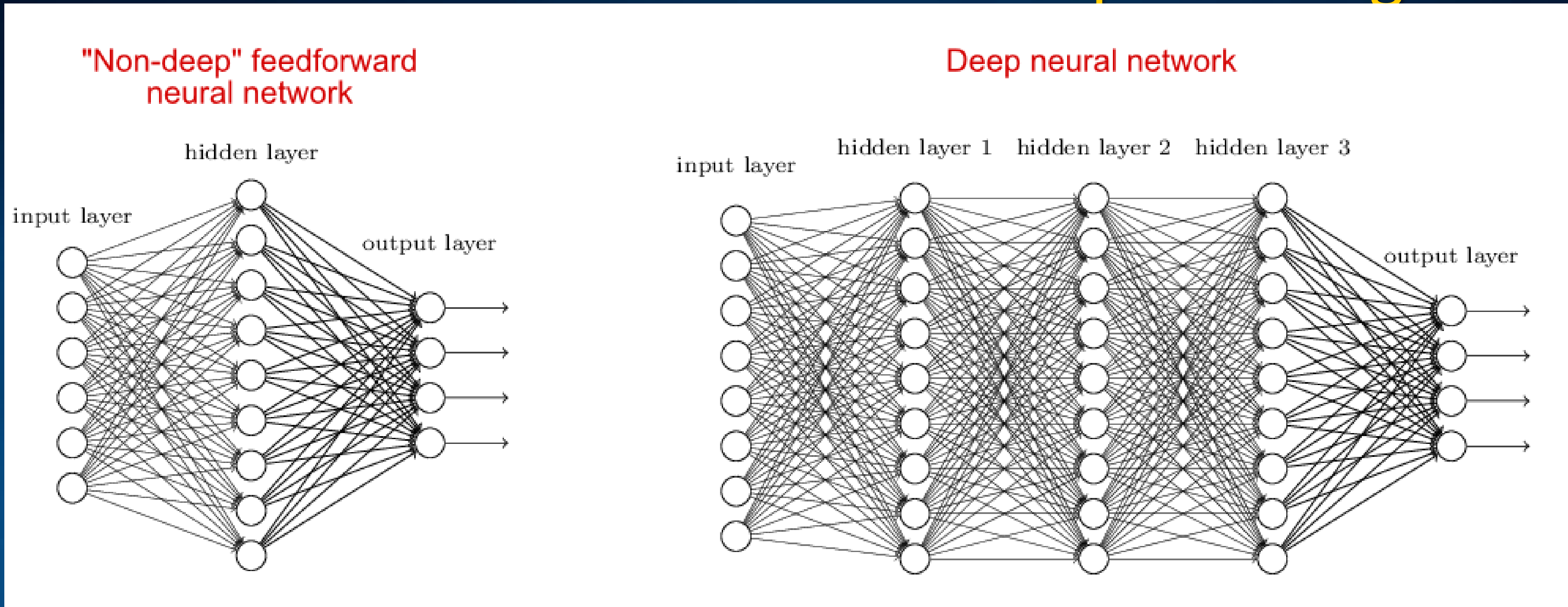


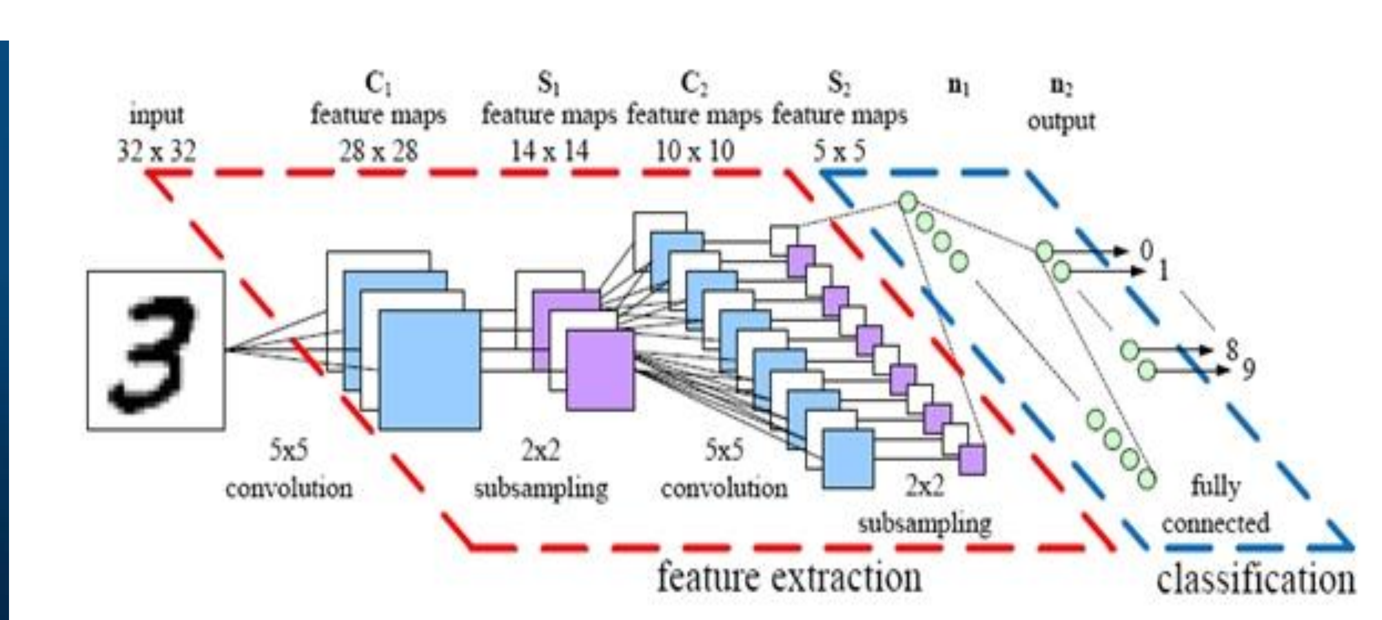




Exploratory and multi-way blind source separation and tensor factorizations: unsupervised learning methods and software to find the hidden causes & underlying hidden structure in the data.

Tensorization of Convolutive Deep Learning NN





A. Cichocki Lab
RIKEN BSI

Fingerprints of Mental Activity

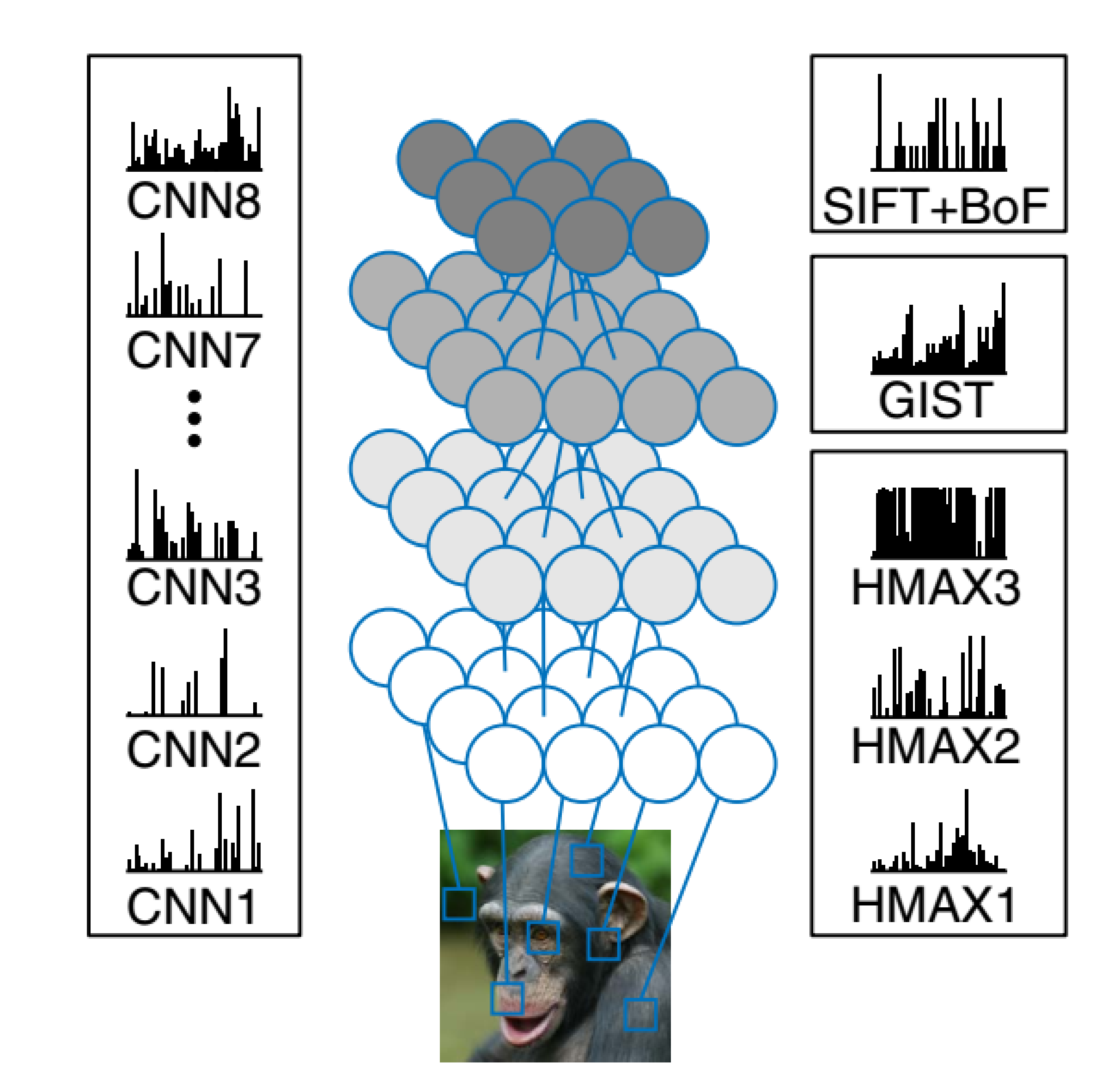
Mental images from brain activity

Can we convert activity of the brain into the mental images that we are conscious of?

Try to estimate features at different layers.

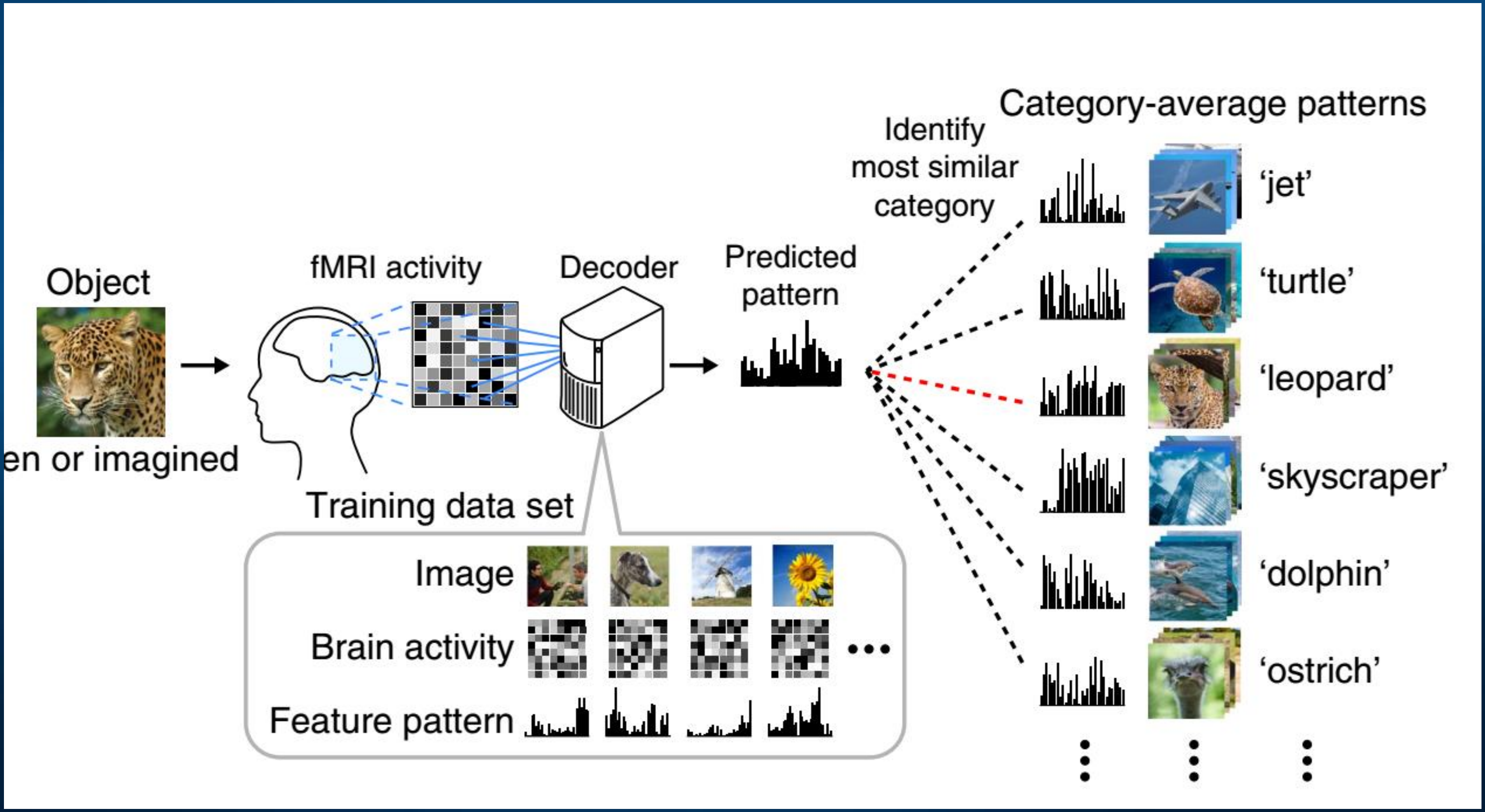
8-layer convolution network, ~60 mln parameters, feature vectors from randomly selected 1000 units in each layer to simplify calculations.

Output: 1000 images.



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 Comm. 2017.



Decoding Dreams

Decoding Dreams, ATR Kyoto, Kamitani Lab. fMRI images analysed during REM phase or while falling asleep allows for dream categorisation.

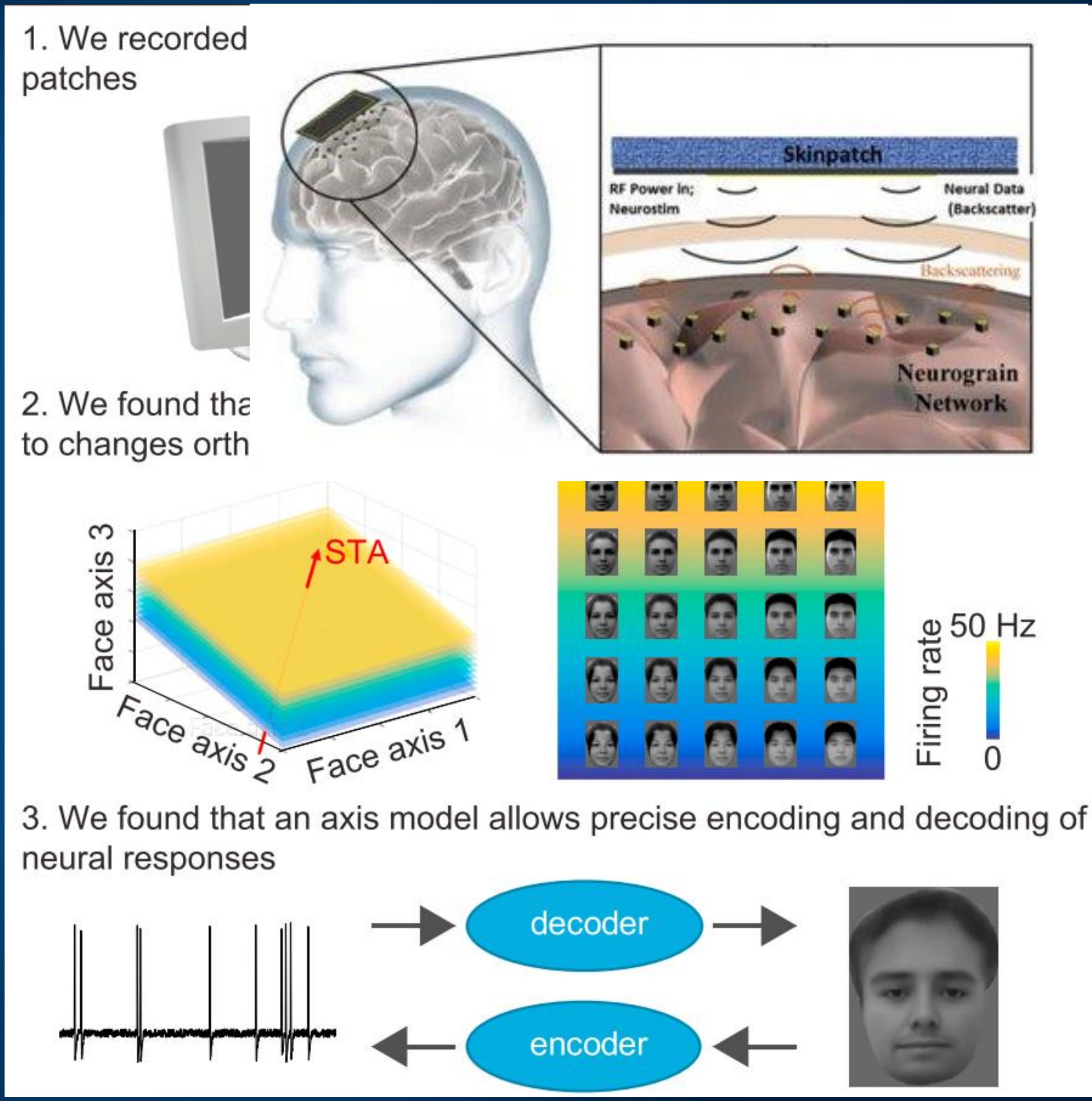
Dreams, thoughts … can one hide what has been seen and experienced?

Neural screen

Features are discovered, and their combination remembered as face, but detailed recognition needs detailed recording from neurons – 205 neurons in various visual areas used.

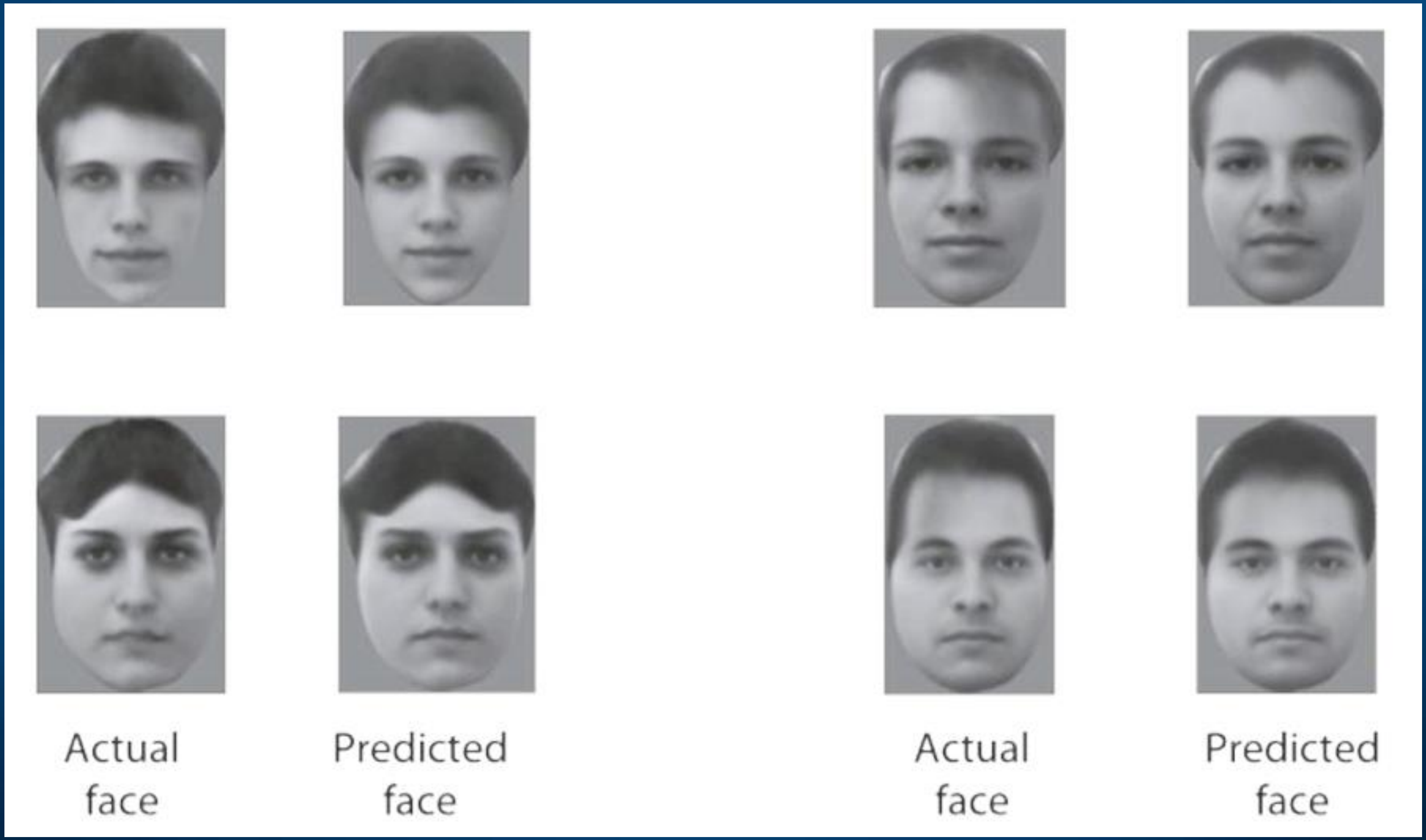
L. Chang and D.Y. Tsao, "The code for facial identity in the primate brain," *Cell* 2017

DARPA (2016): put million nanowires in the brain! Use them to read neural responses and 10% of them to activate neurons.

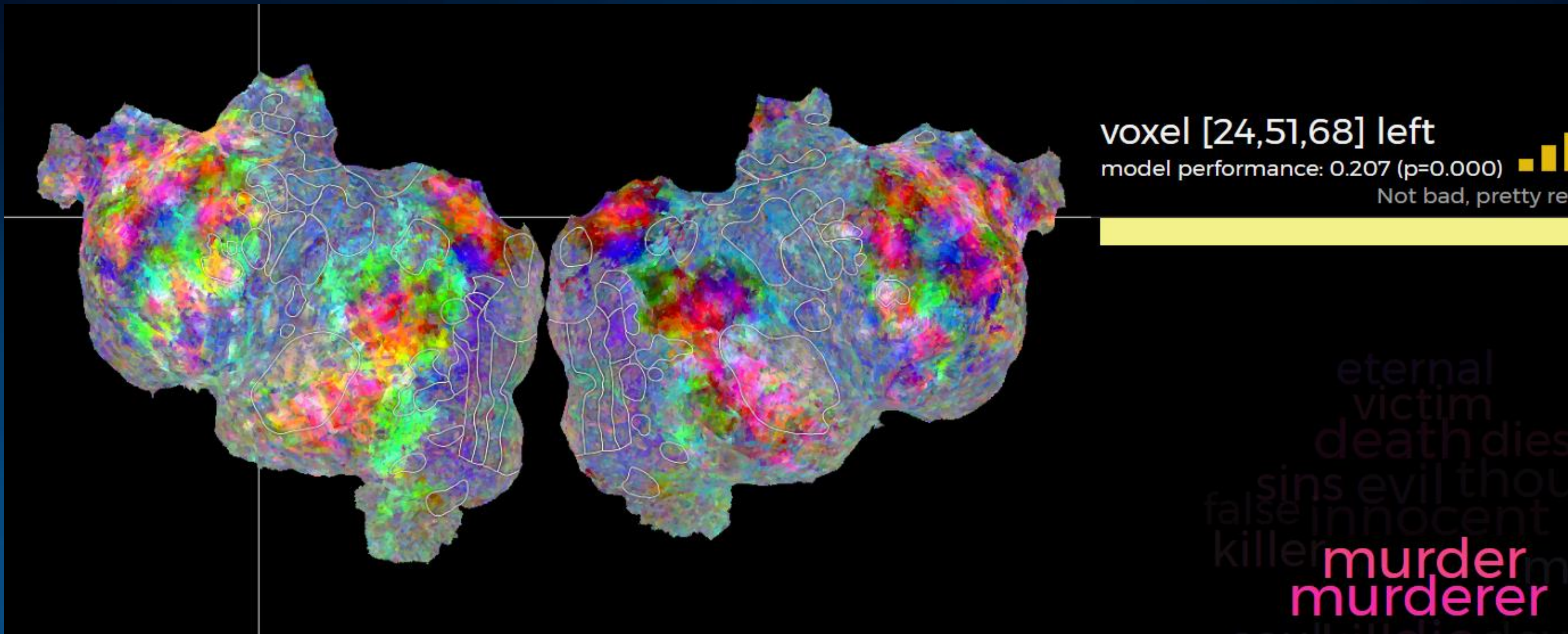


Mental images

Facial identity is encoded via a simple neural code that relies on the ability of neurons to distinguish facial features along specific axes in the face space.



L. Chang and D.Y. Tsao, *Cell* 2017

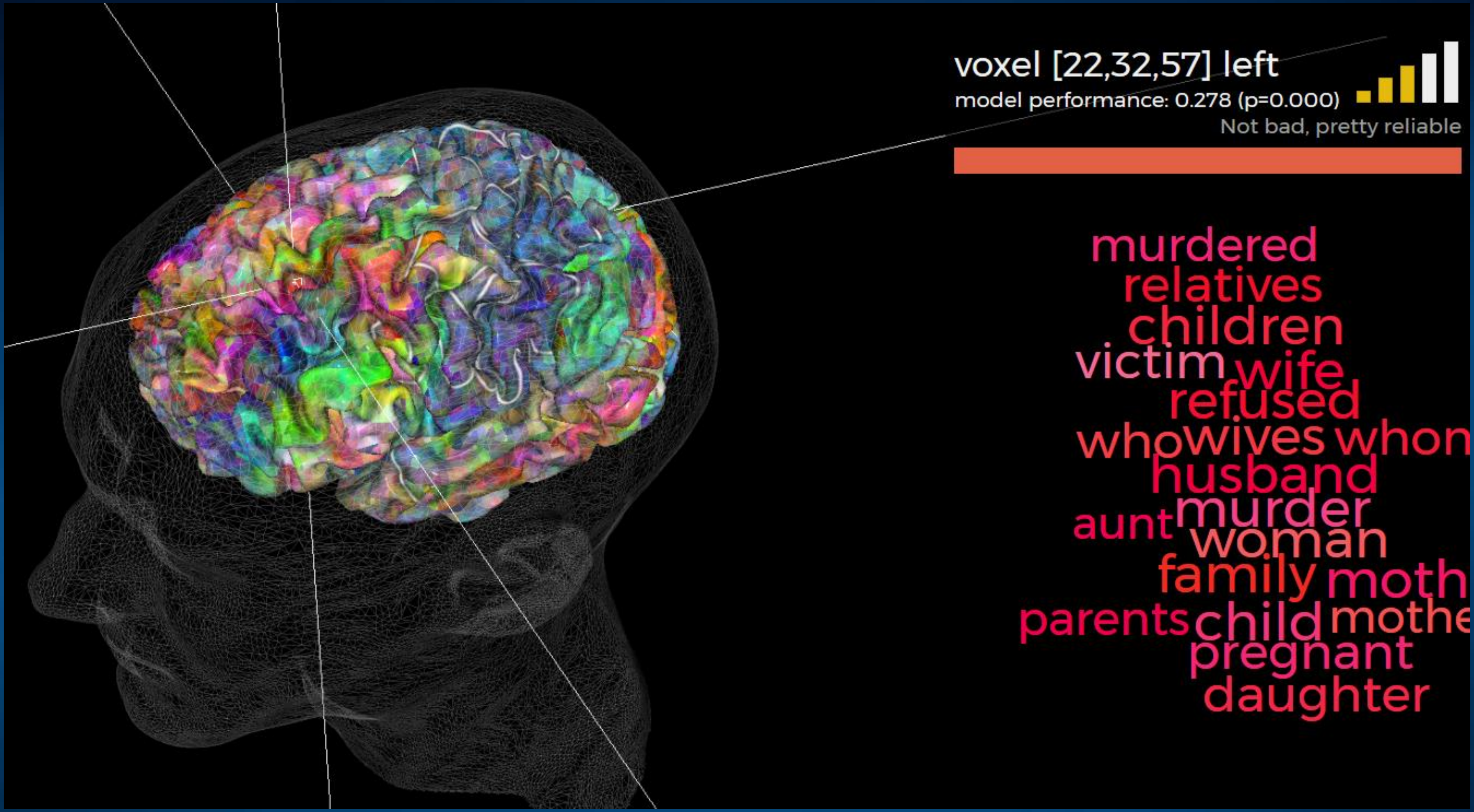


Whole fMRI activity map for the word "murder" shown on the flattened cortex.

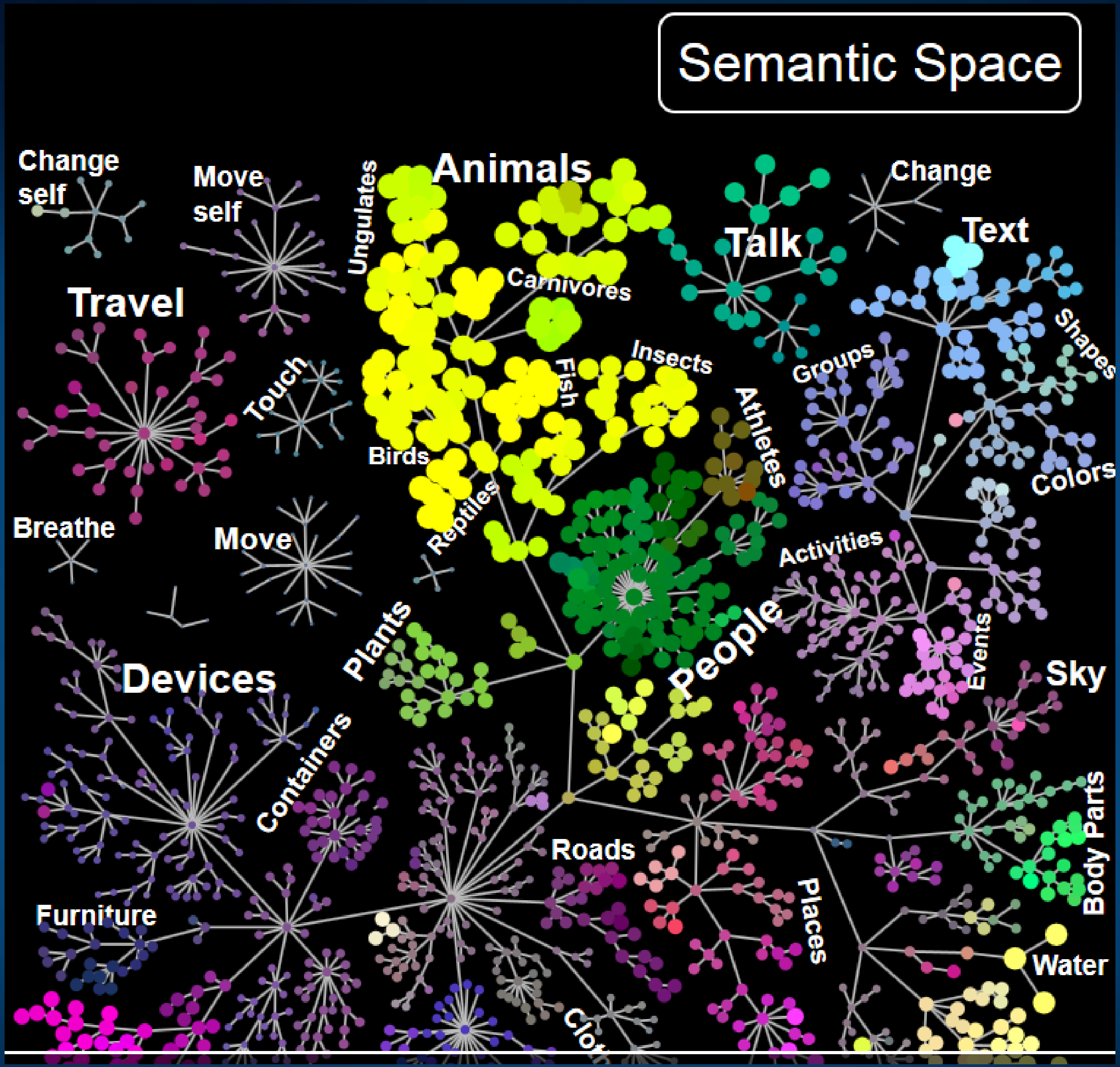
Each word activates a whole map of activity in the brain, depending on sensory features, motor actions and affective components associated with this word. Why such activity patterns arise? Brain subnetworks connect active areas.

http://gallantlab.org/huth2016/ and short movie intro.

Can one do something like that with EEG or MEG?



Each voxel responds usually to many related words, whole categories.
http://gallantlab.org/huth2016/
Huth et al. (2016). Decoding the Semantic Content of Natural Movies from Human Brain Activity. Frontiers in Systems Neuroscience 10, pp. 81



Words in the semantic space are grouped by their similarity (Gallant Lab, 2016).
Words activate specific ROIs, similar words create similar maps of brain activity.
Each voxel may be activated by many words. Video or audio stimuli, fMRI scans.

Narration

Nicole Speer et al.
Reading Stories Activates Neural Repre-sentations of Visual and Motor Experiences. Psychological Science 2009; 20(8): 989–999.

Thought: spatiotemporal pattern

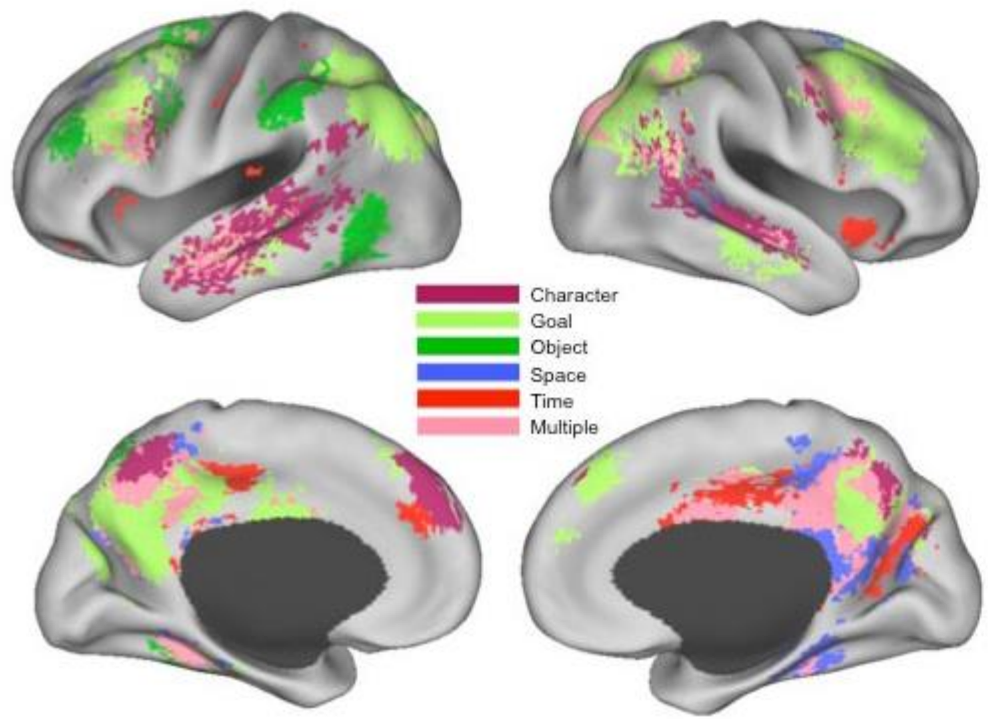
Meaning: always slightly different, depending on the context, but still may be clustered into relatively small number of distinct meanings.

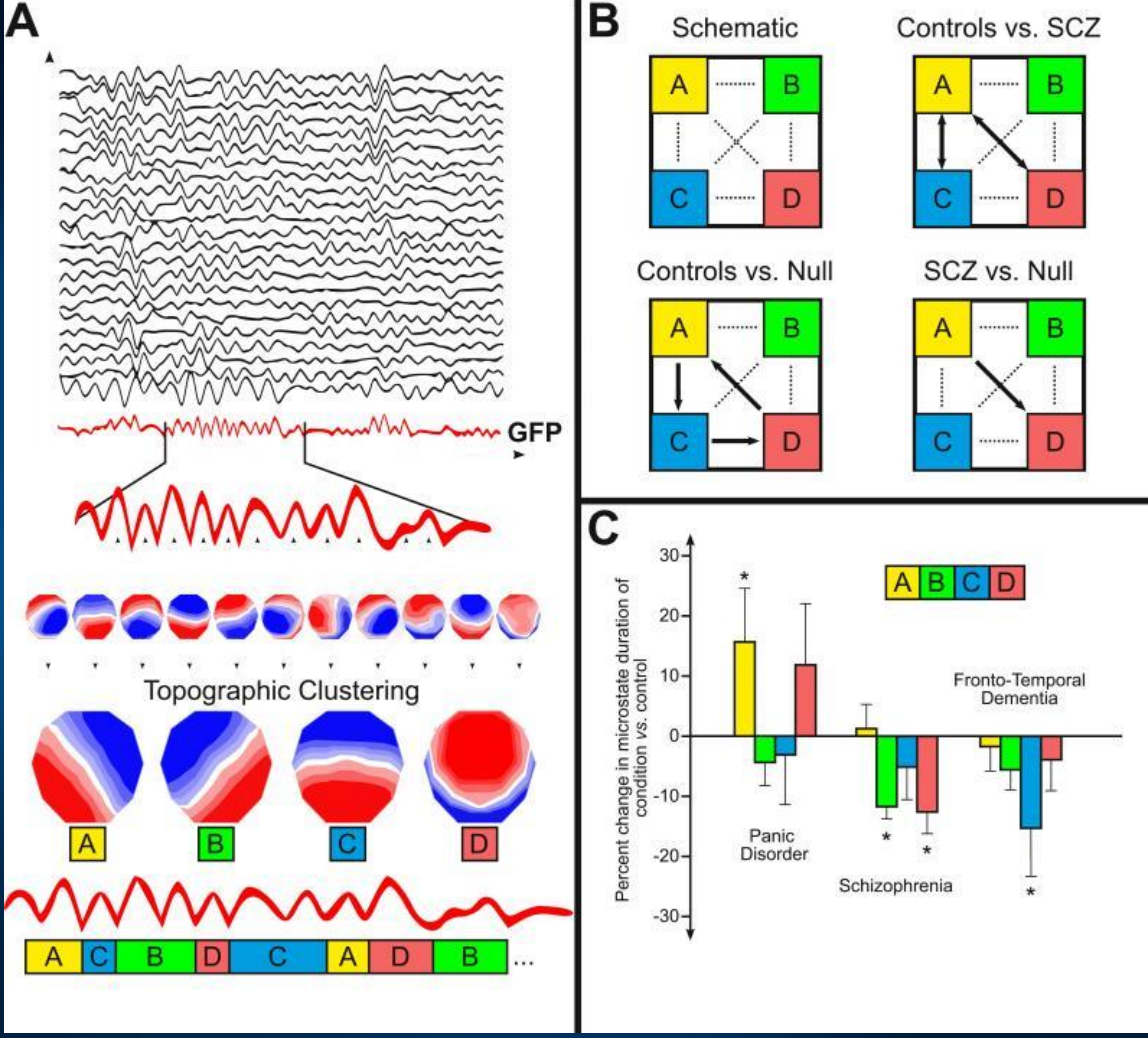
Sentences: trajectories in semantic space, building scenes, mind models with characters, objects, spatio-temporal relations.

A

Clause	Cause	Character	Goal	Object	Space	Time
...[Mrs. Birch] went through the front door into the kitchen.	●				●	
Mr. Birch came in	●	●			●	
and, after a friendly greeting,	●					●
chatted with her for a minute or so.	●					●
Mrs. Birch needed to awaken Raymond.		●				
Mrs. Birch stepped into Raymond's bedroom,			●		●	
pulled a light cord hanging from the center of the room,				●		
and turned to the bed.						
Mrs. Birch said with pleasant casualness,						
"Raymond, wake up."						
With a little more urgency in her voice she spoke again:						
Son, are you going to school today?						
Raymond didn't respond immediately.		●				●
He screwed up his face			●			
And whimpered a little.						

B




A
GFP
Topographic Clustering
A
B
C
D
A C B D C A D B ...
B
Schematic
Controls vs. SCZ
Controls vs. Null
SCZ vs. Null
C
Percent change in microstate duration of condition vs. control
30
20
10
0
-10
-20
-30
Panic Disorder
Schizophrenia
Fronto-Temporal Dementia

Model of reading & dyslexia

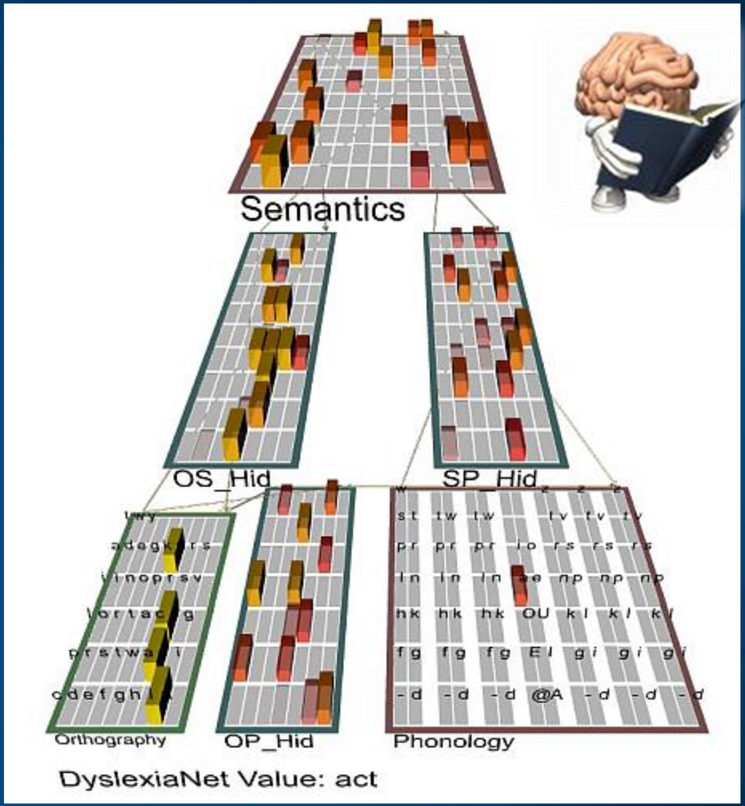
Emergent neural simulator:

Aisa, B., Mingus, B., and O'Reilly, R. The emergent neural modeling system. Neural Networks, 21, 1045, 2008.

3-layer model of reading:

orthography, phonology, semantics, or distribution of activity over **140 microfeatures** defining concepts.

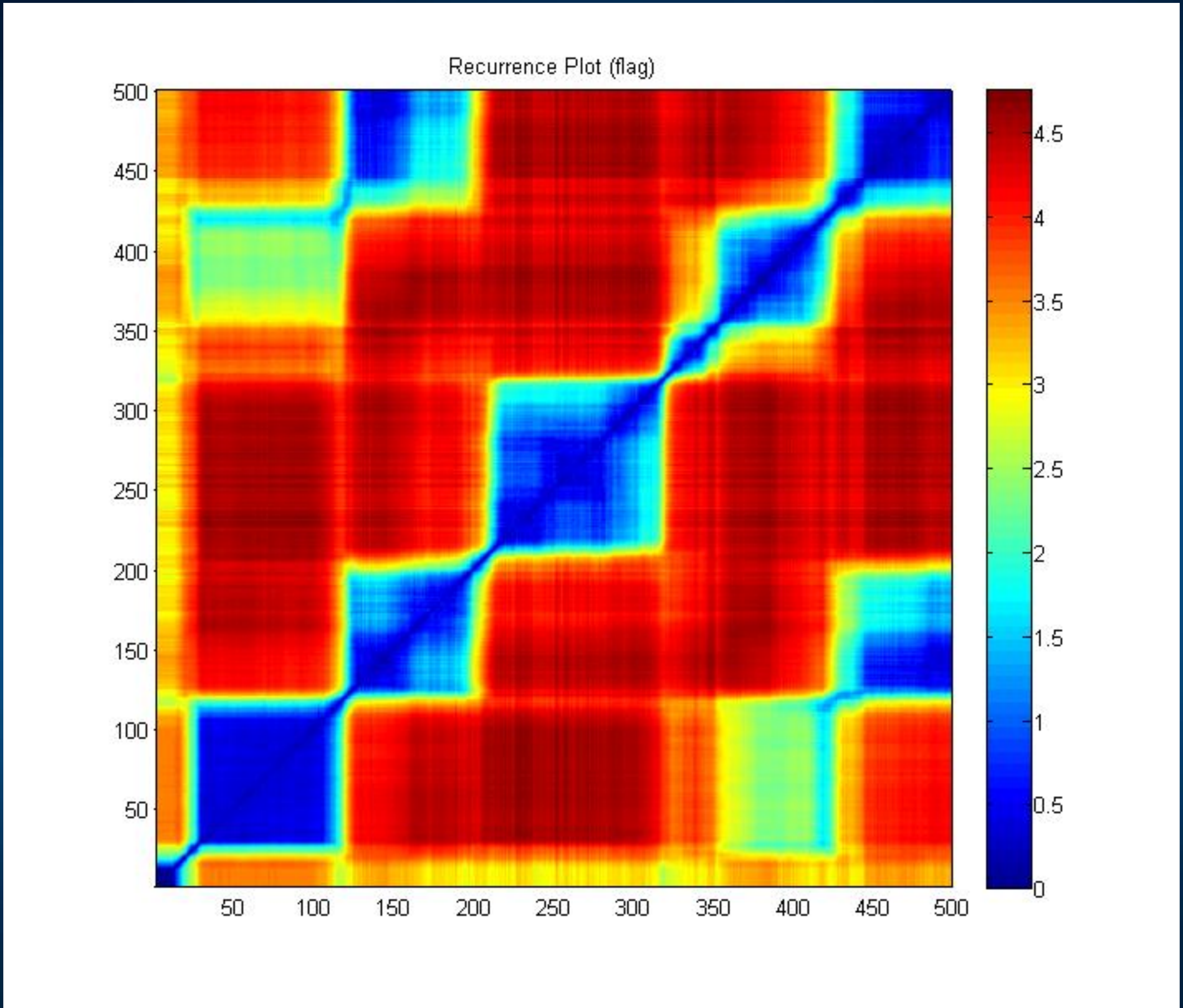
In the brain: microfeature=subnetwork.
Hidden layers OS/OP/SP_Hid in between.



Learning: mapping one of the 3 layers to the other two.

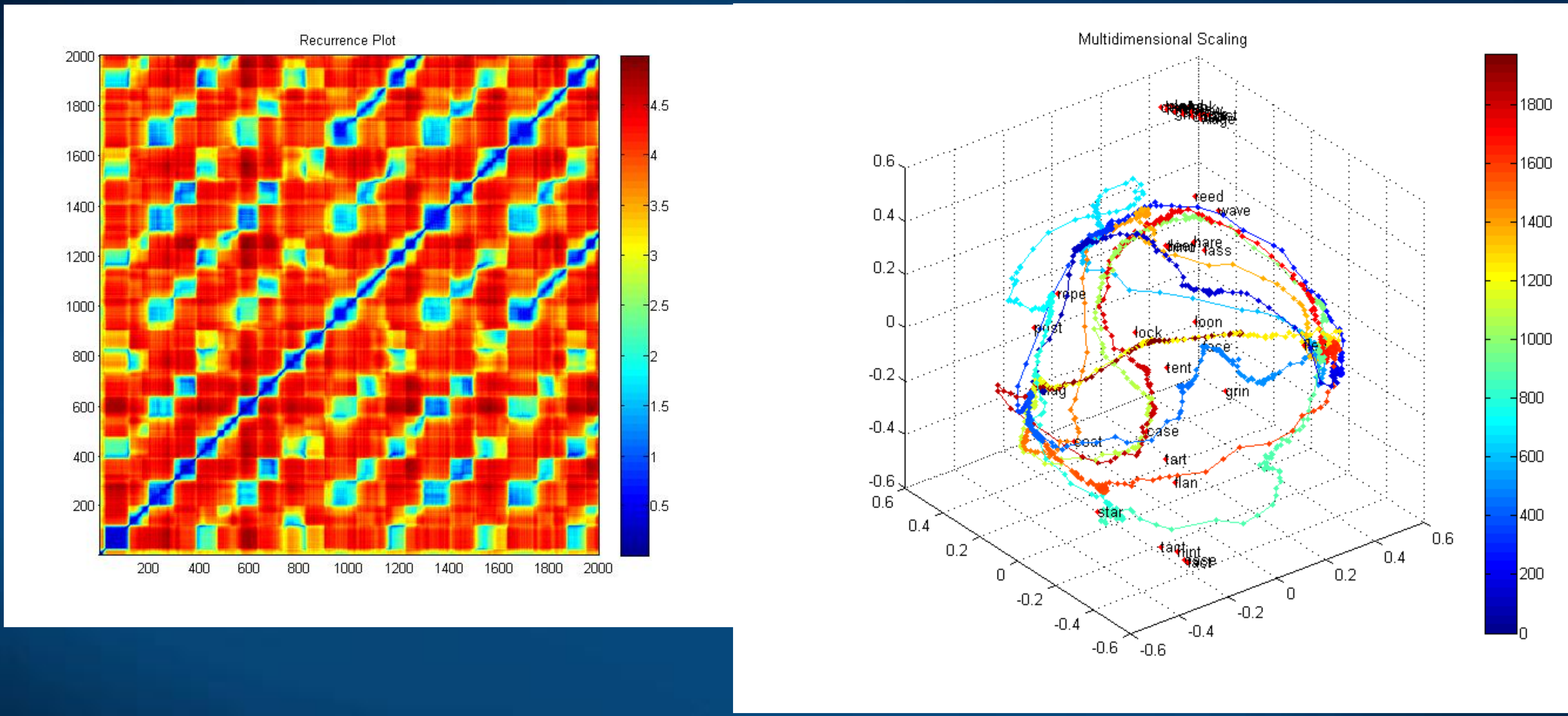
Fluctuations around final configuration = attractors representing concepts.

How to see properties of their basins, their relations?
Model in **Genesis**: more detailed neuron description.



Recurrence Plot (flag)
500
450
400
350
300
250
200
150
100
50
50
100
150
200
250
300
350
400
450
500
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0

Trajectory visualization



Recurrence plots and MDS/FSD/SNE visualization of trajectories of the brain activity. Here data from 140-dim semantic layer activity during spontaneous associations in the 40-words microdomain, starting with the word "flag".
Our toolbox: http://fizyka.umk.pl/~kdobosz/visertoolbox/

Possible form of Brain Fingerprints

fMRI: BFP is based on **V(X,t)** voxel intensity BOLD signal changes, contrasted between task and reference activity or resting state.
EEG: spatial, spatio-temporal, ERP maps/shapes, coherence, various phase synchronization indices.

1. **Spatial/Power**: direct localization/reconstruction of sources.
2. **Spatial/Synch**: changes in functional graph network structure.
3. **Frequency/Power**: ERS/ERD smoothed patterns E(X,t,f).
4. **ERP power maps**: spatio-temporal averaged energy distributions.
5. **EEG decomposition into components:** ICA, CCA, tensor, RP ...
6. **EEG** microstates, sequences & transitions, dynamics in ROI space.
7. Model-based: **The Virtual Brain**, integrating EEG/neuroimaging data.
8. Spectral fingerprinting (MEG, EEG), power distributions.

Neuroplastic changes of connectomes and functional connections as results of training for optimization of brain processes.

Dynamic functional brain networks

Questions

Global Neuronal Workspace Theory (Deahene et al. 1998): brain processes underlying effortful tasks require two main computational spaces:

- a set of specialized and modular perceptual, motor, memory, evaluative, and attentional processors;
- a unique global workspace composed of distributed and heavily interconnected neurons with long-range axons.

Workspace neurons are mobilized in effortful tasks for which the specialized processors (System 1) do not suffice (Kahneman's System 2), mobilize or suppress contribution of specific processor neurons.

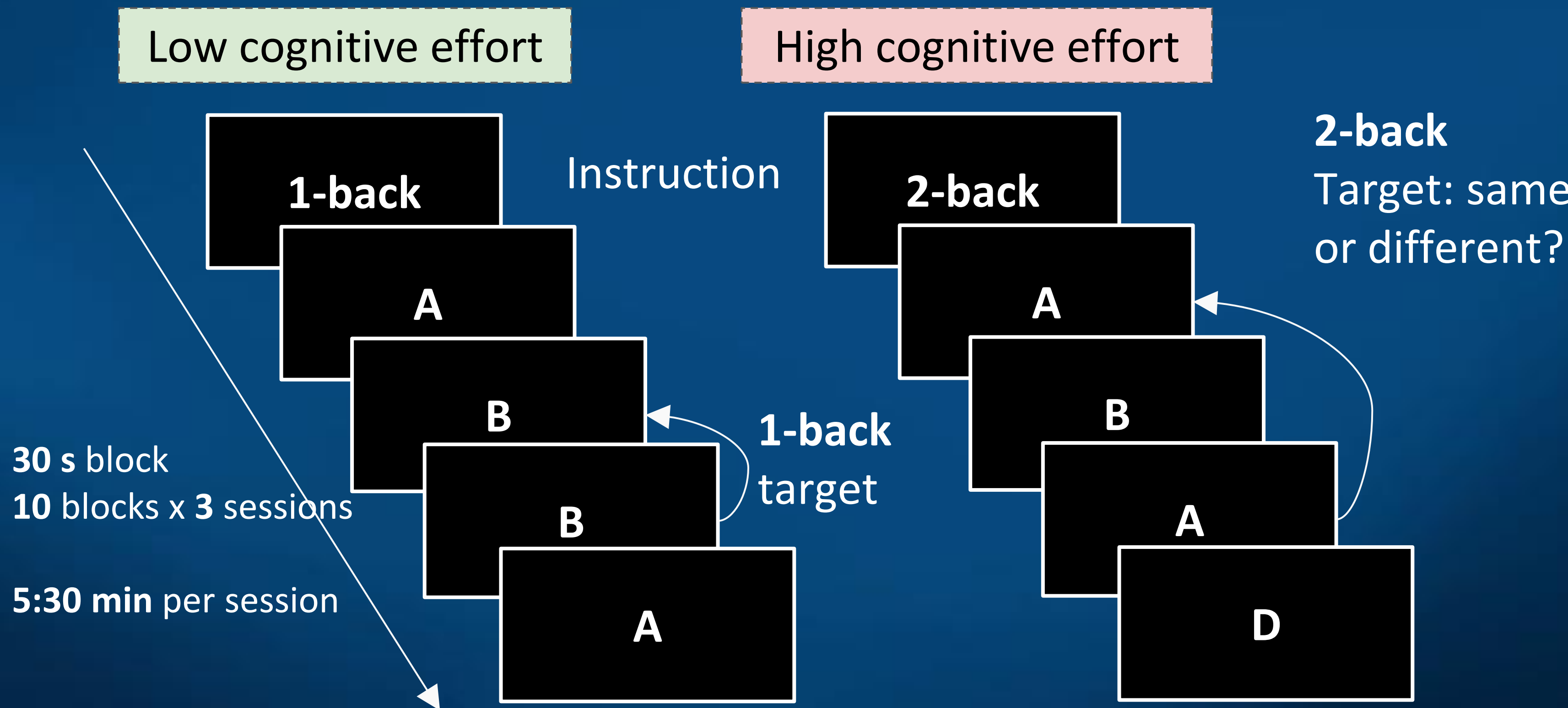
1. Can the whole-brain network properties change during performance?
2. Is modularity, path length, global and local efficiency dependent on the cognitive load?

Finc, K., Bonna, K., Lewandowska, M., Wolak, T., Nikadon, J., Dreszer, J., Duch W, Kühn, S. (2017). Transition of the functional brain network related to increasing cognitive demands. Human Brain Mapping, 38(7), 3659–3674.

Cognitive load on whole-brain network

35 participants (17 females; Mean age = 22.6 ± 3.1; 19-31).

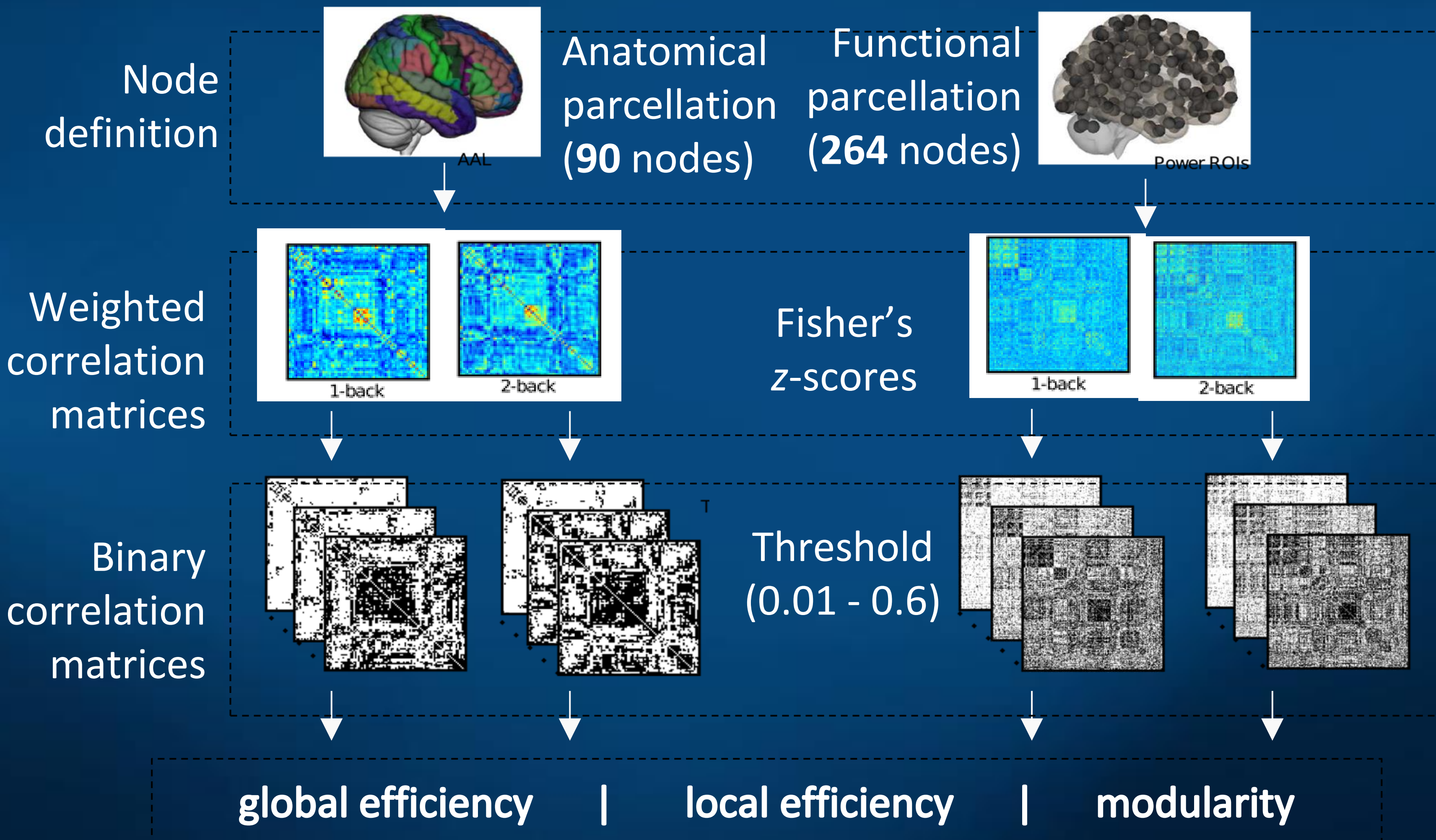
Letter *n*-back task



Finc et al, Human Brain Mapping, 2017

Data workflow

Two experimental conditions: 1-back, 2-back



Brain modules and cognitive processes

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

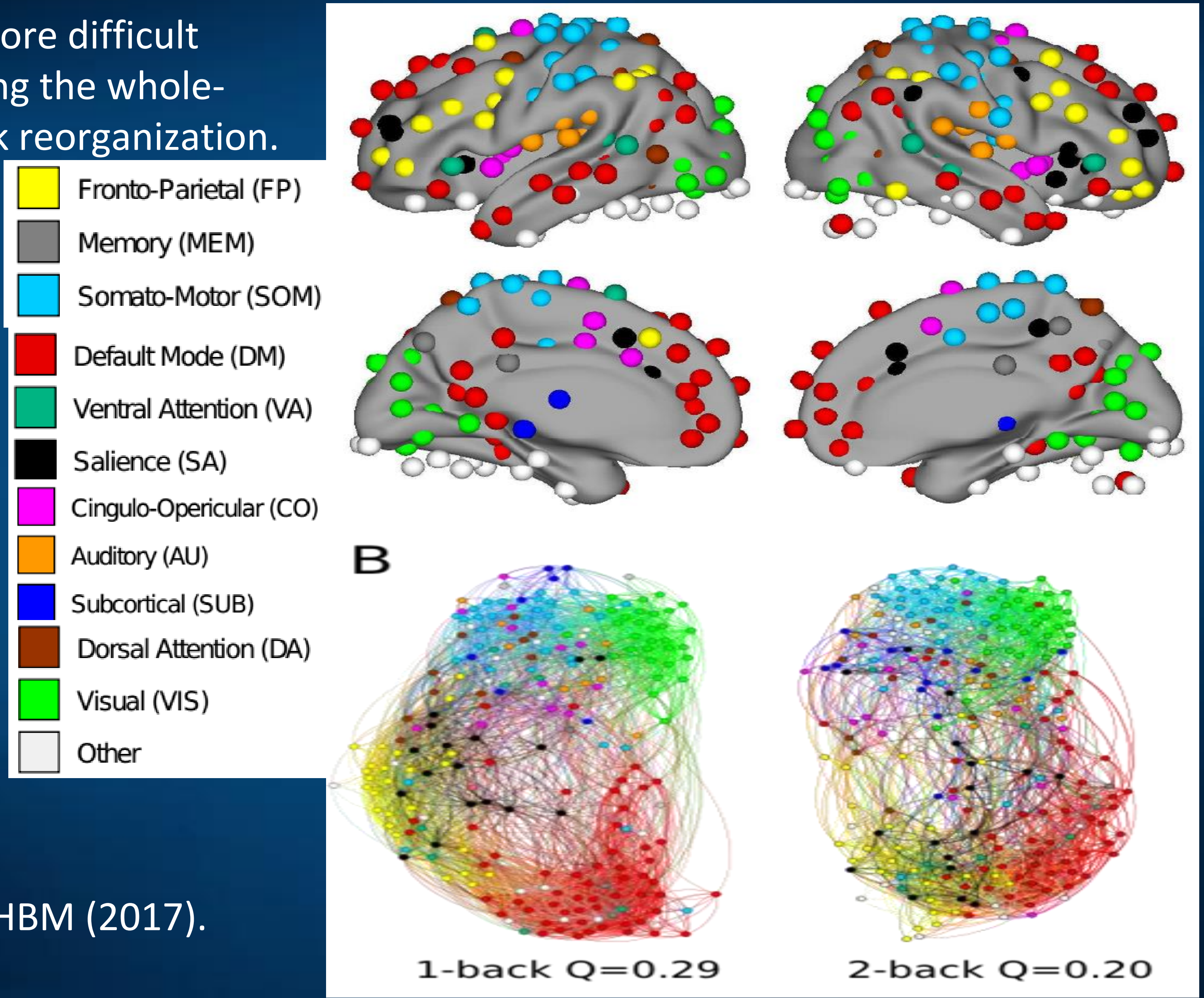
Left: 1-back

Right: 2-back

Average over 35 participants.

Left and midline sections.

K. Finc et al, HBM (2017).



Brain modules and cognitive processes

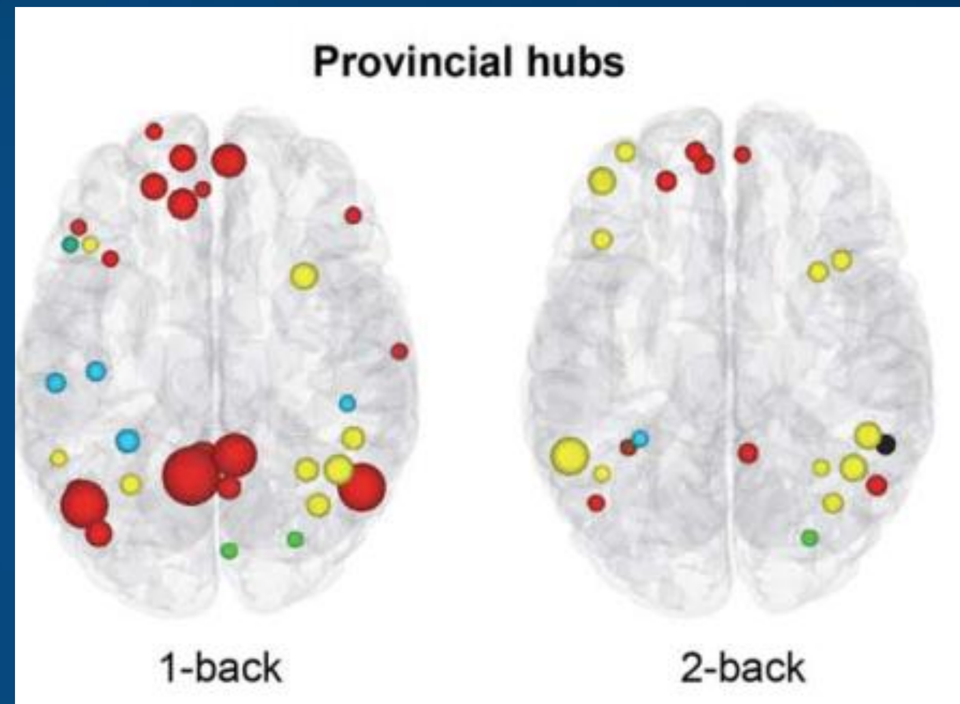
Simple and more difficult tasks, requiring the whole-brain network reorganization.

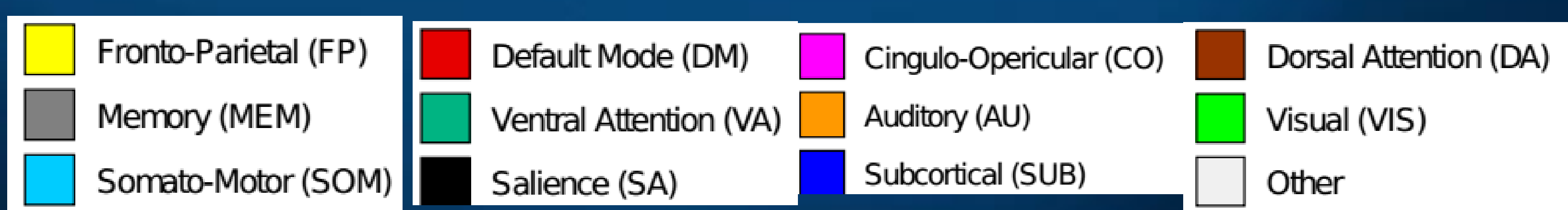
Left: 1-back local hubs

Right: 2-back local hubs

Average over 35 *participants.*

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





K. Finc et al, HBM (2017).

Brain modules and cognitive processes

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

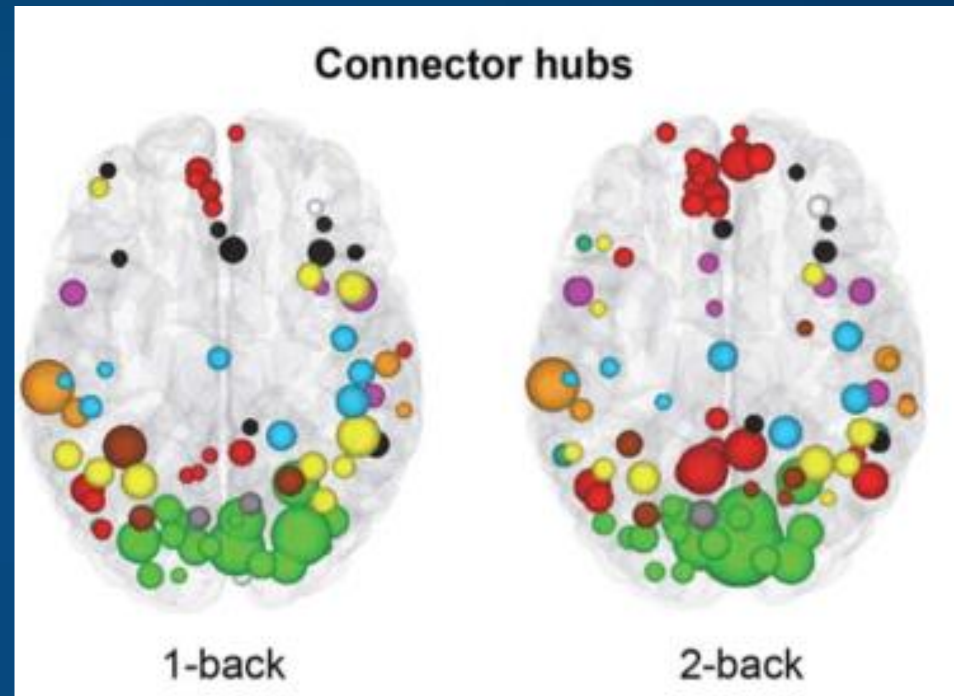
Left: 1-back connector hubs

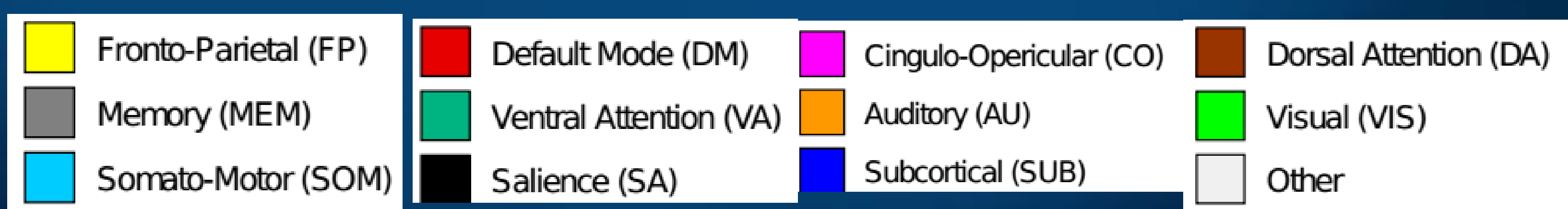
Right: 2-back connector hubs

Average over 35 *participants.*

Dynamical change of the landscape of attractors, depending on the cognitive load – System 2 (Khaneman).

DMN areas engaged in global binding!





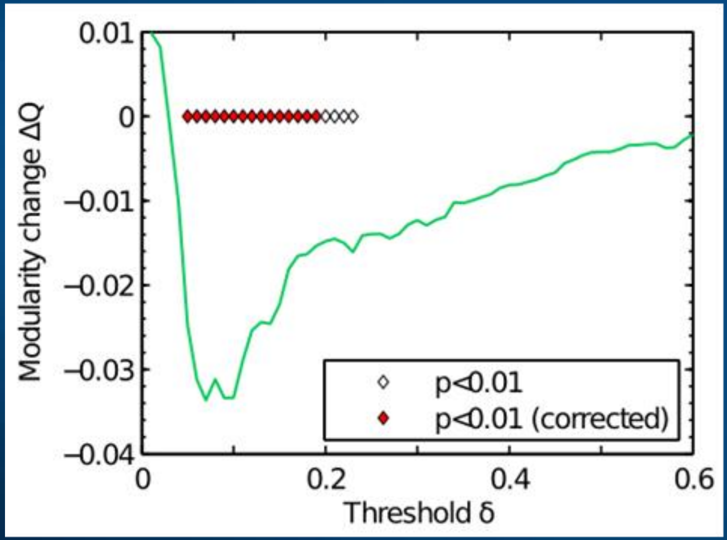
K. Finc et al, HBM (2017).

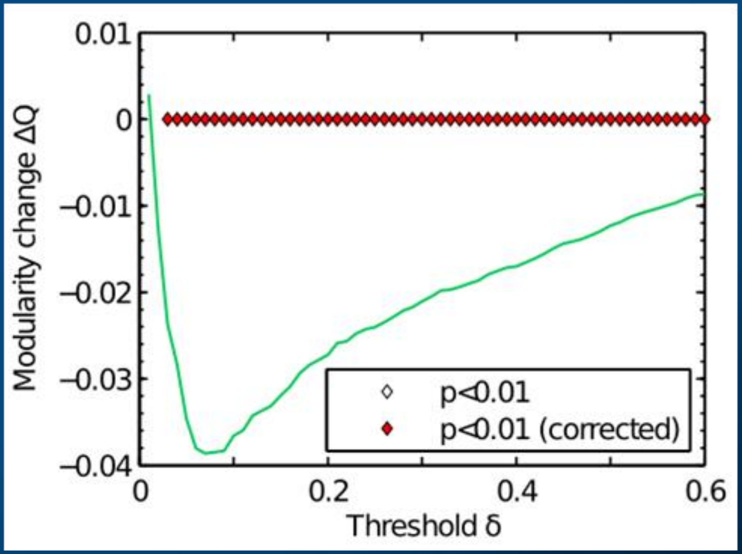
Changes in modularity

Modularity metric: fraction of within-community edges in the network minus such fraction for randomly connected network with unchanged community structure.

Parcellation
AAL, 90 ROI

Parcellation
264 ROI
functional





Modularity for both parcellations significantly decreases for thresholds ~0.1.
Coarse parcellation washes out many effects, especially strong correlations.

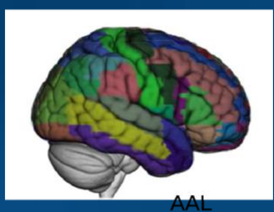
Finc et al, Human Brain Mapping, 2017

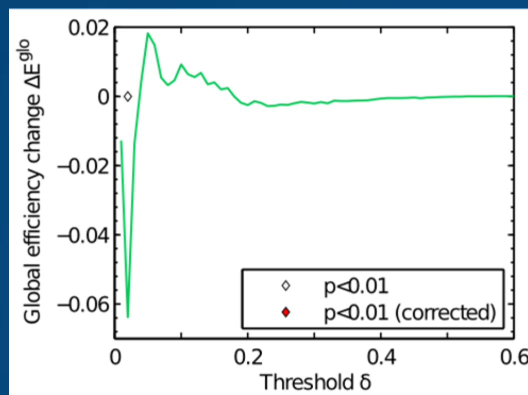
Changes in efficiency

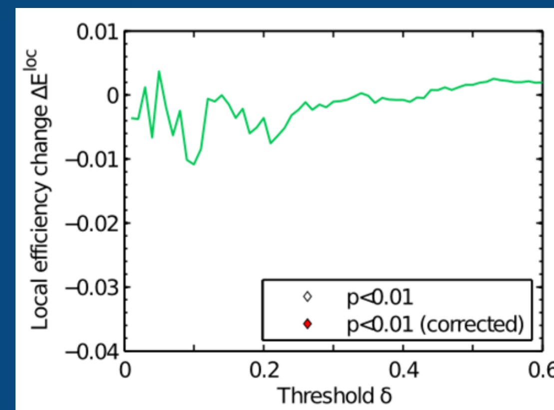
Global efficiency ~ inverse of characteristic path length
Local efficiency ~ clustering coefficient (Latora & Marchiori, 2001).

Global efficiency

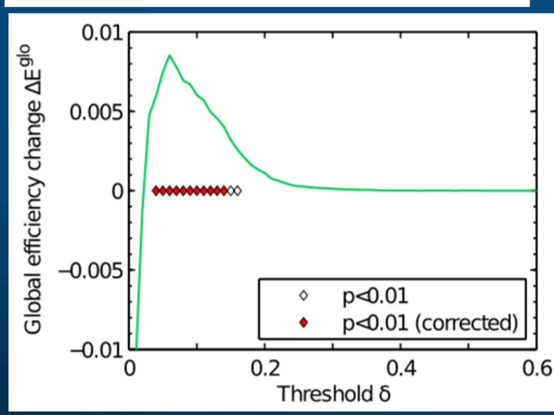
Local efficiency

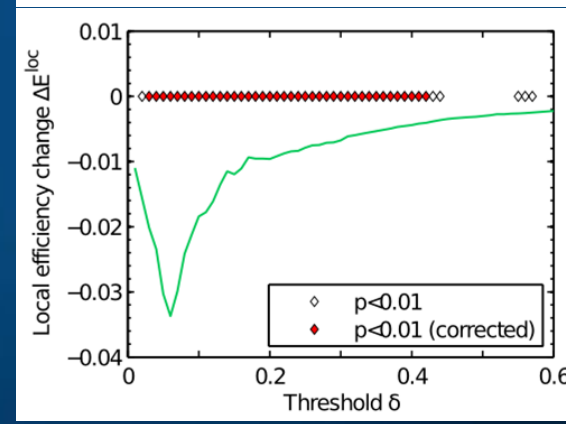






Parcellation
AAL, 90 ROI





Parcellation
264 ROI
functional

Finc et al, Human Brain Mapping, 2017

Cognitive load

Low cognitive effort

- Segregated network
- Locally specialized processing

High cognitive effort

- Integrated network
- Distributed processing

↑ global efficiency

↓ local efficiency

↓ modularity

↓ performance

≠

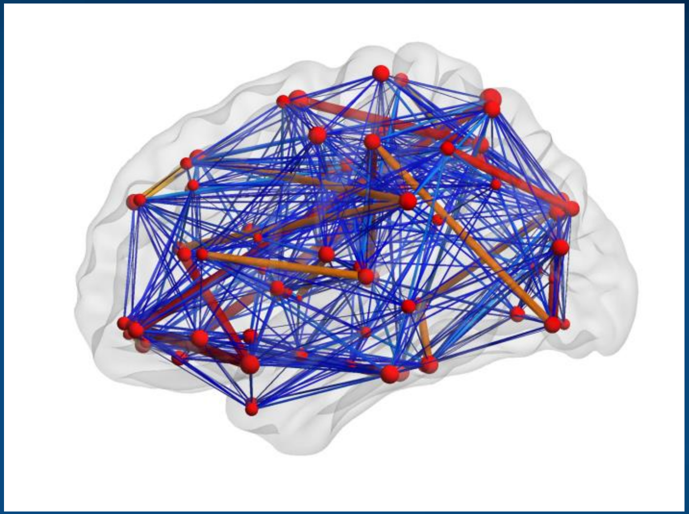
Parcellation into 264 regions (10 mm spheres) shows subnetworks more precisely than for 90 regions; only a small subgroup of neurons in each ROI is strongly correlated.

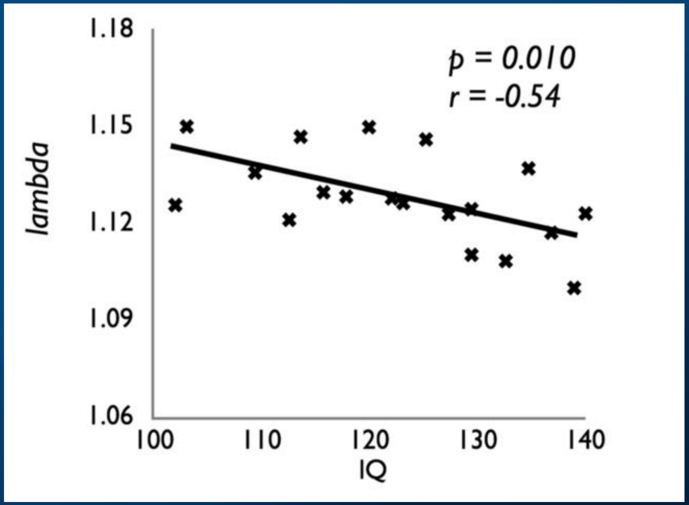
Resting state/cognitive performance

Characteristic path length λ → Intellectual performance

Modularity → Working memory performance

Modularity → Working memory capacity





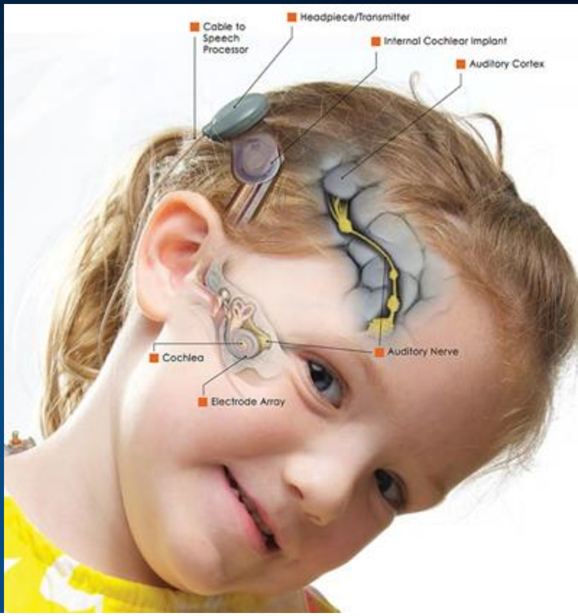
Network modularity ⇔ higher working memory capacity and performance.

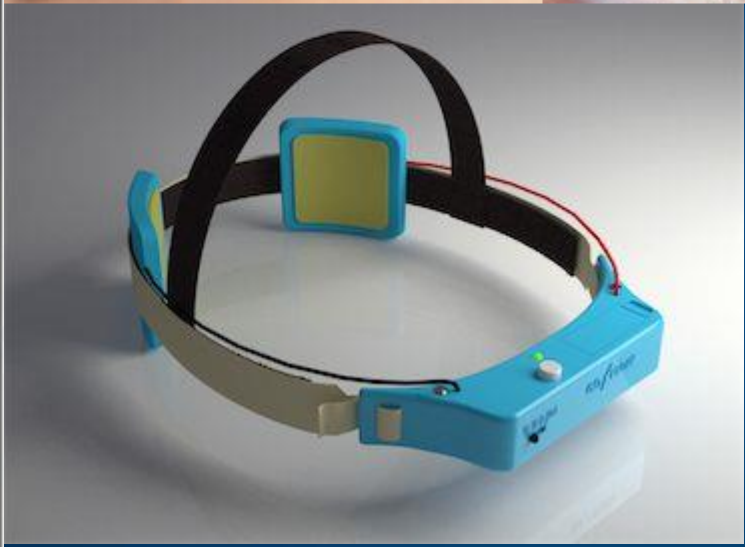
High connectivity within modules and sparse connections between modules increases effective cooperation of brain regions, is associated with higher IQ.

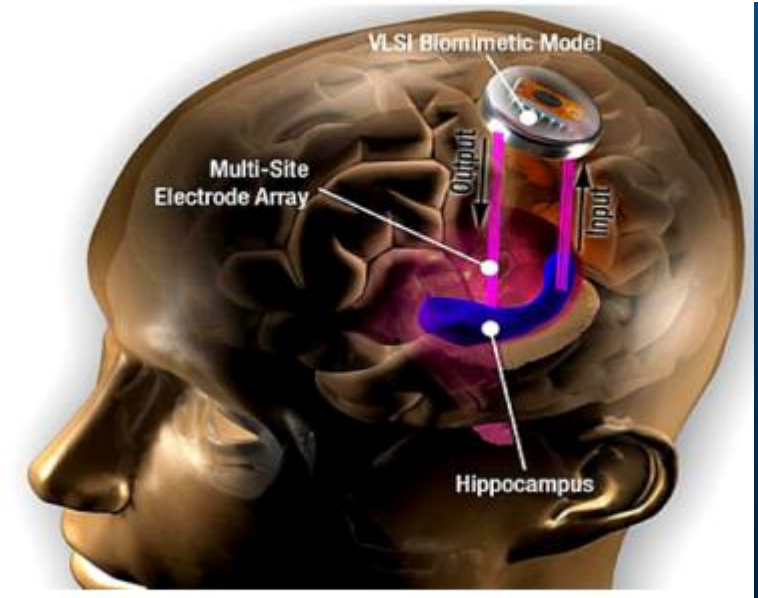
van den Heuvel *et al.* (2009) | Stevens *et al*. (2012)

Human Enhancement
and
Optimization of Brain Processes

Enhancing Perception



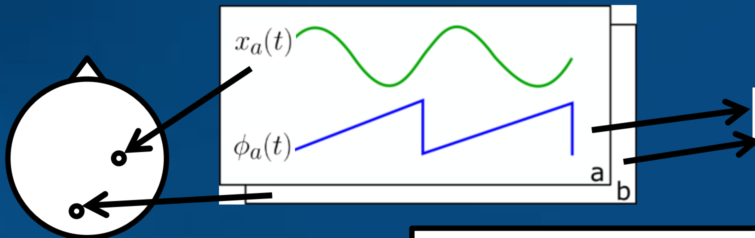




Improving eyes, ears, touch, but also memory and attention skills…
Implantation of new neurons in the brain?

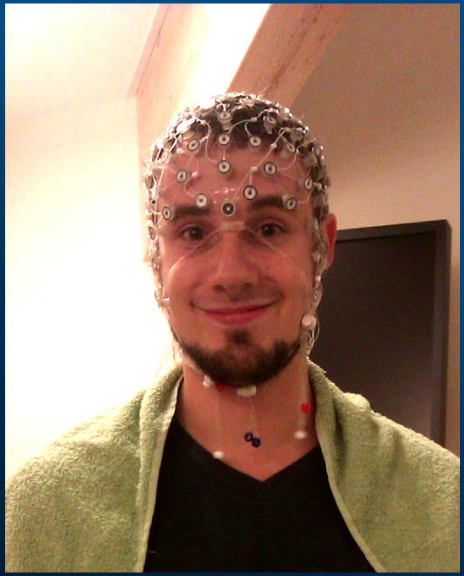
Functional connectivity changes

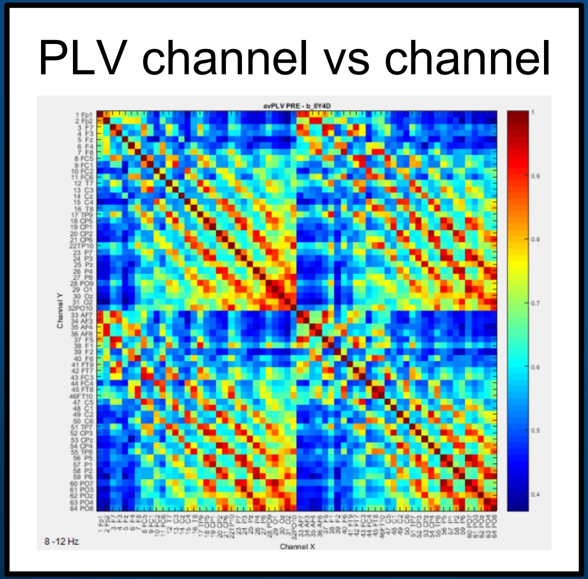
Influence of brain games on functional connectivity: **Phase Locking Value** (Burgess, 2013; Lachaux 1999), phase differences between signals measured at each electrode. PLV => synchronization maps, info flow.

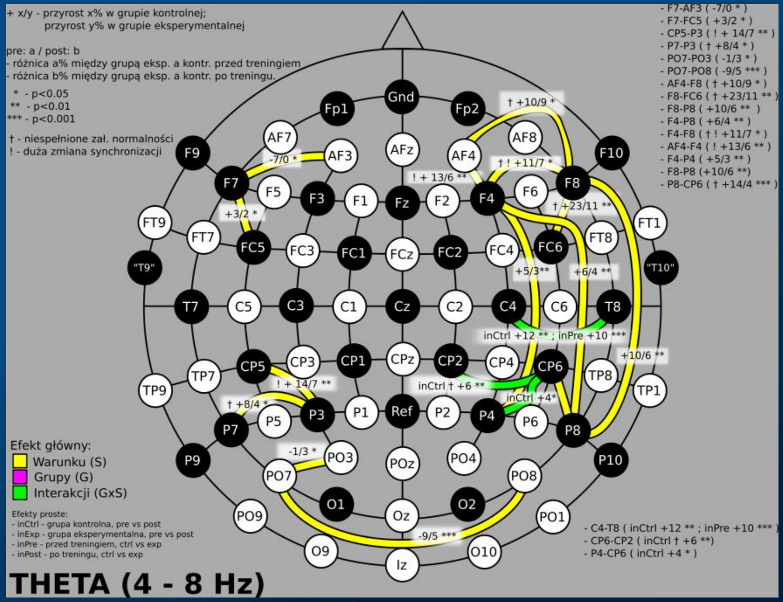


$$\Phi(t) = \phi_a(t) - \phi_b(t)$$

$$PLV(a,b) = \frac{1}{T}\left|\sum_{t}^{T} e^{i\Phi(t)}\right|$$







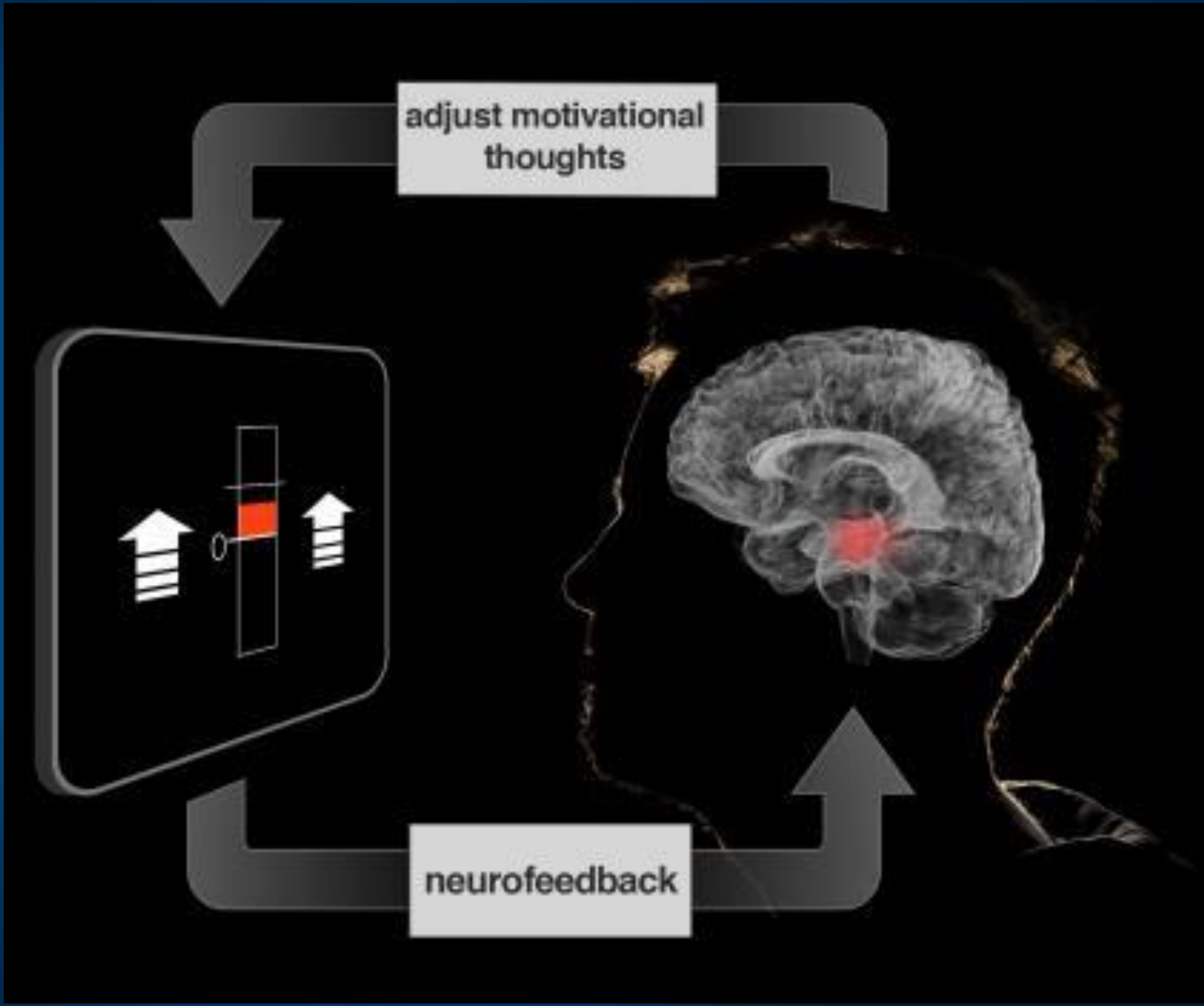
Neurofeedback: first BCI

Used in clinical practice, α/θ rhythms for relaxation.

Duch, Elektronika i stresy, 1978!

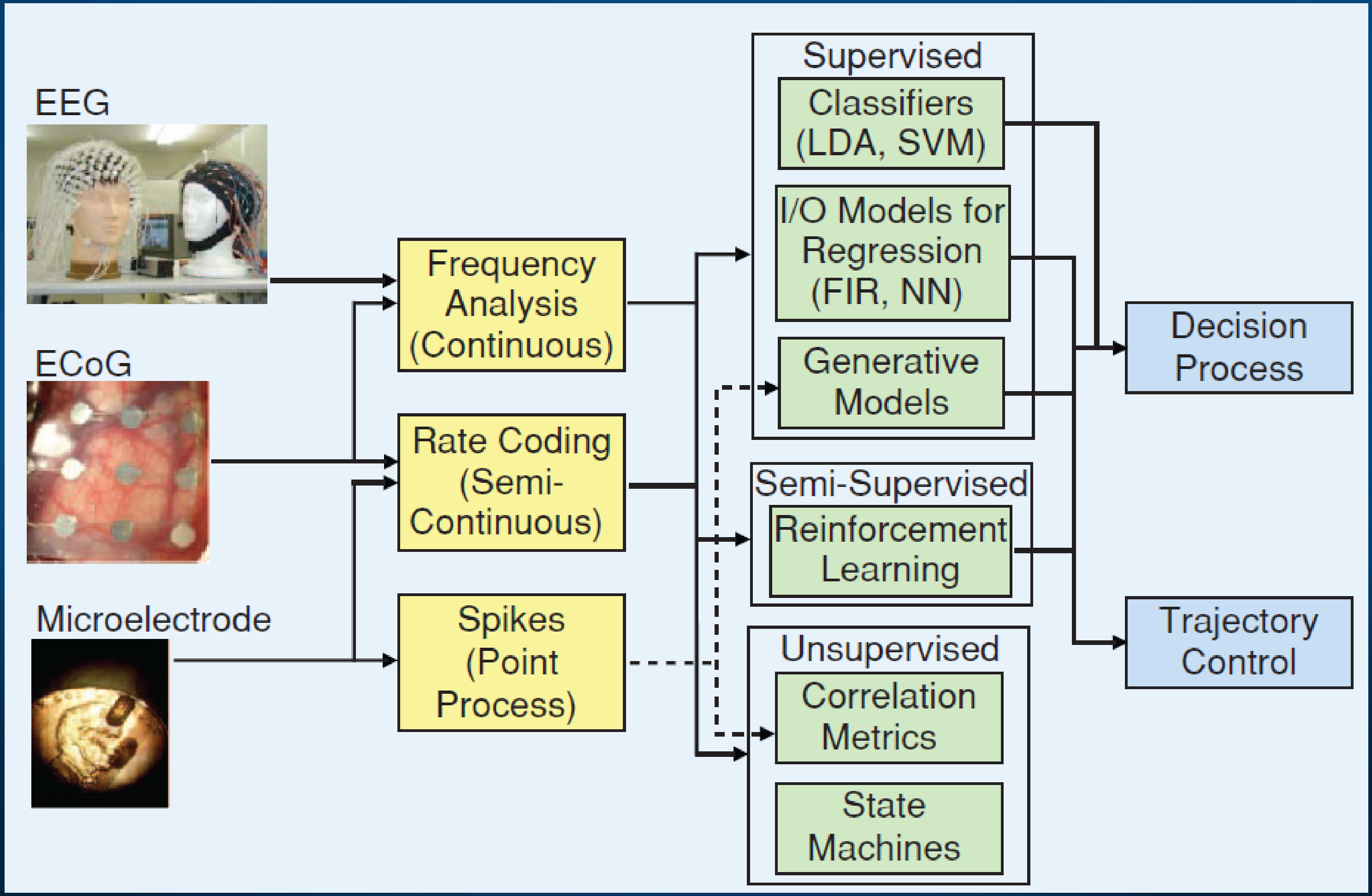
Critical review of existing literature shows that this is not effective.

New forms based on brain fingerprinting needed.

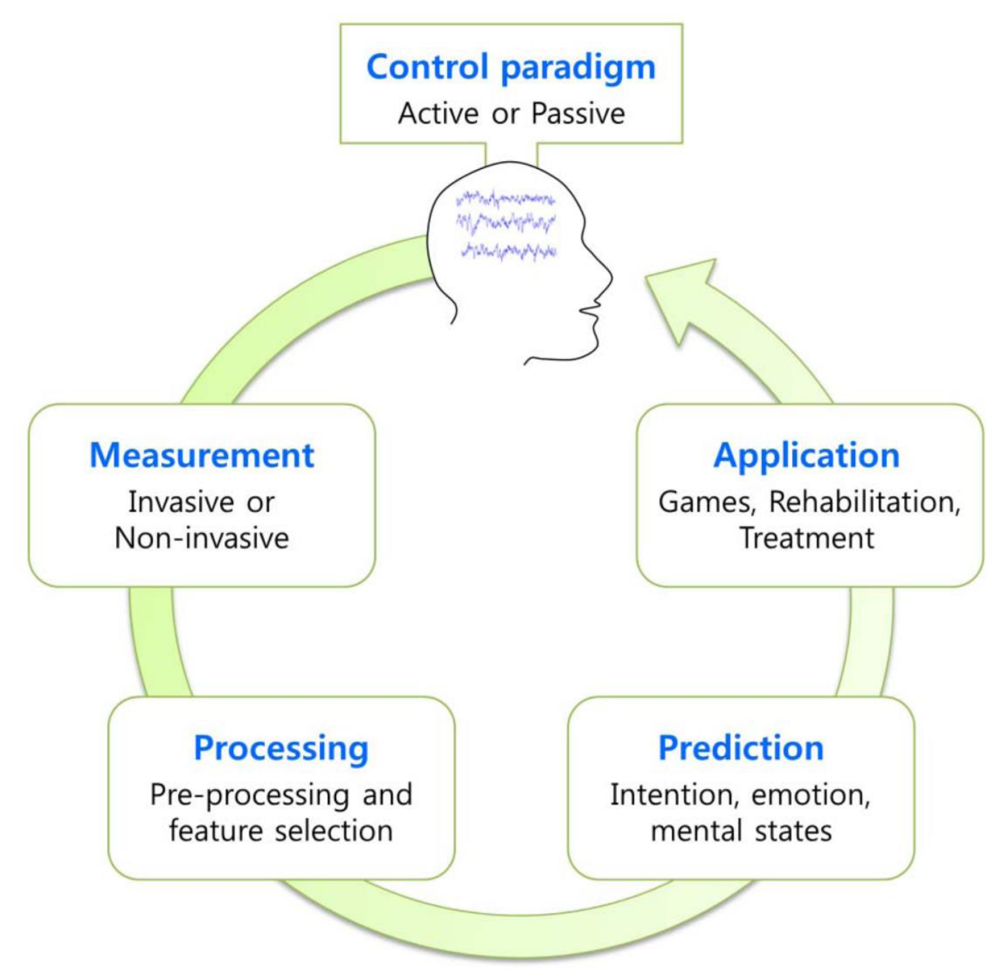


BCI: wire your brain …

Non-invasive, partially invasive and invasive signals carry progressively more information, but are also harder to implement. EEG is the king!



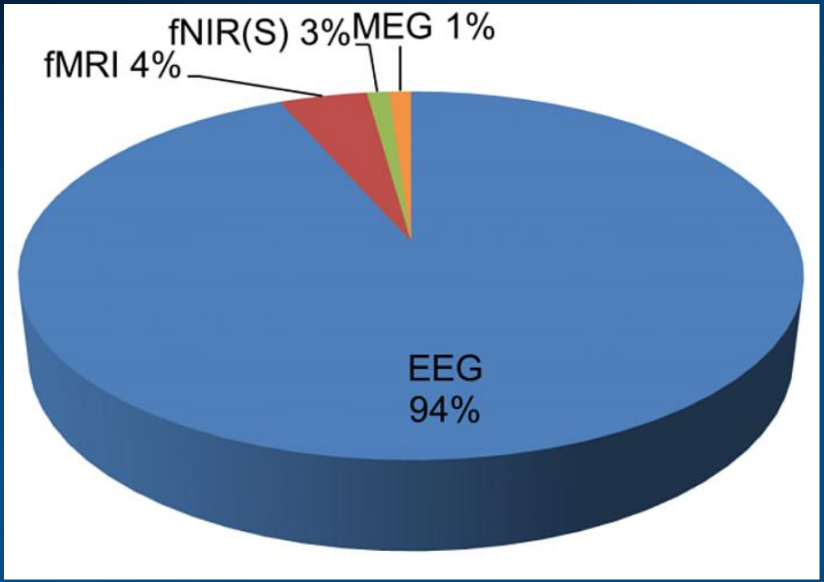
Features of BCI

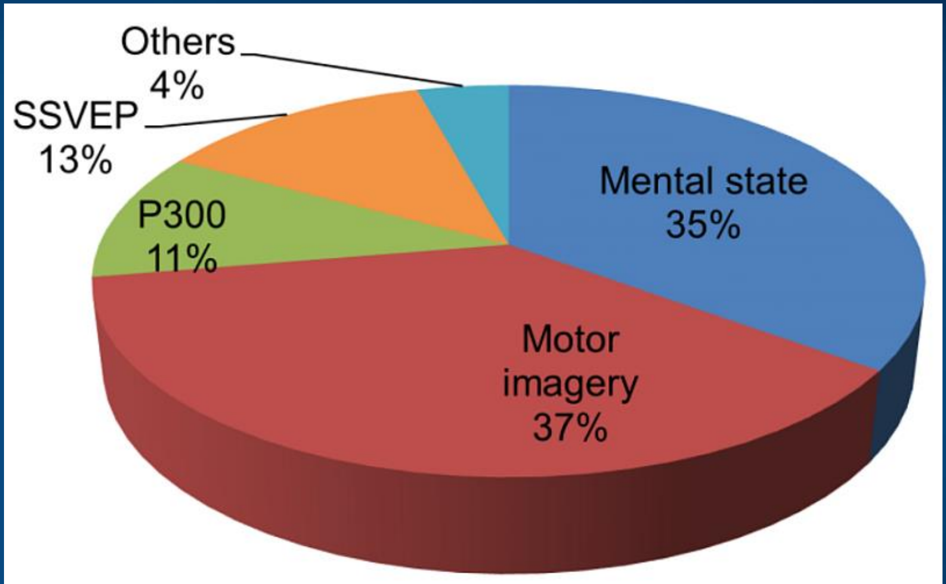


Source: Ahn et al. (2014) *Sensors*, *14*(8), 14601–14633.

BCI Infographics from Futurism.com shows a good summary.

Signal source





In BCI research EEG is used most frequently, it may also be used wirelessly.

SSVEP, Steady State Visual Evoked Potentials, is perhaps the simplest.

Mental state is frequently based on emotions or attention.

Brain-Computer Interfaces

BCI is a XXI century science, only a few papers were written in XX century.

In the last decade EU contributed over 50M Euro for BCI research.

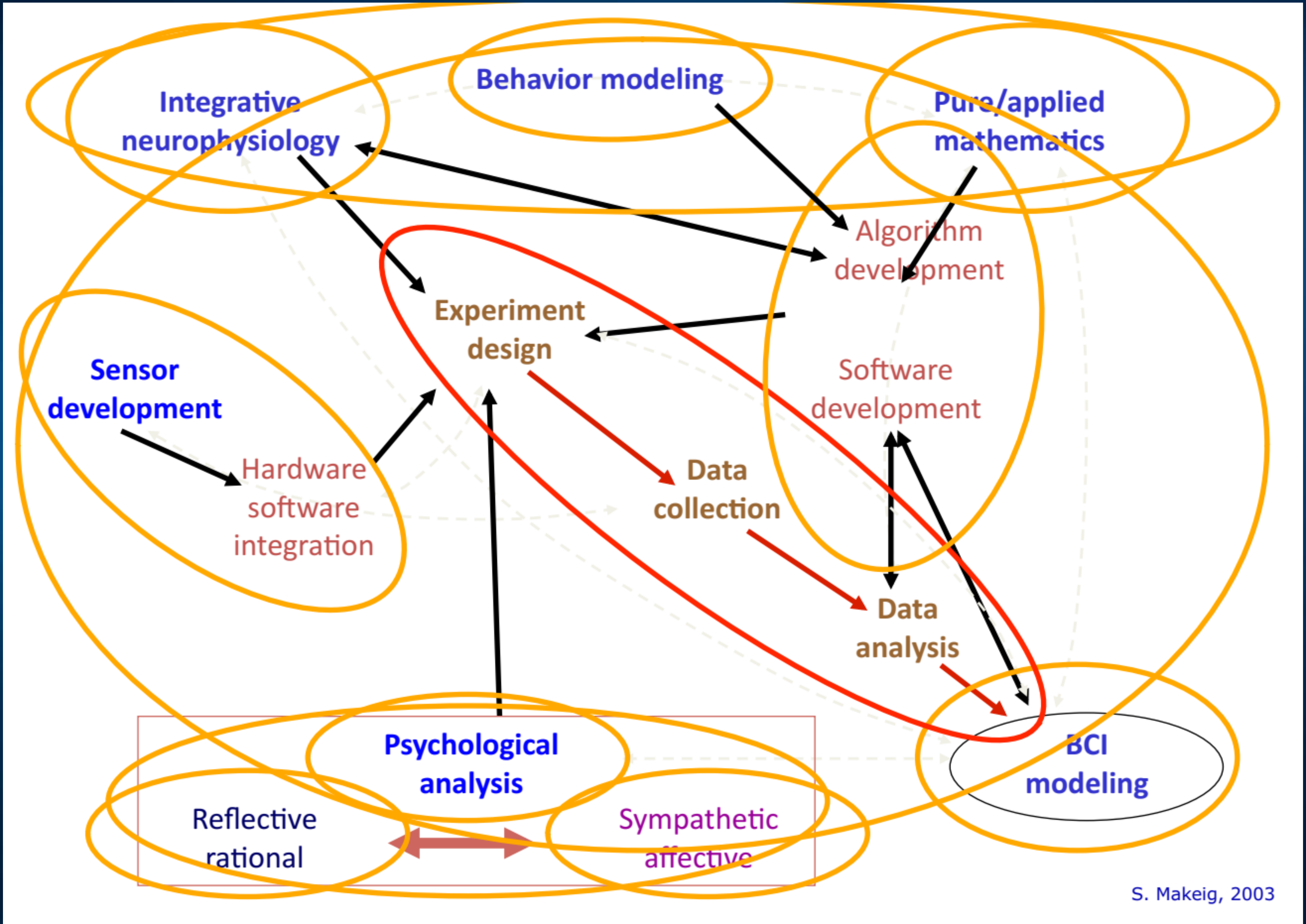
BCI Society: **brain/neuronal computer interaction (BNCI)**, using any kinds of brain and body signals.
BNCI Horizon 2020, lists >100 companies involved in BCI.

Emerging: **Mobile Brain/Body Imaging** (MoBI), recording movement, eye, various biosignals in natural situations.

MoBI: Modeling of human cognitive event-related brain dynamics as captured by high-dimensional EEG, MEG and other imaging modalities including simultaneous eye tracking and body motion capture (Scott Making, UCSD).

Brain-Computer-Brain interfaces, BTBI, or how to change brains …

Interdisciplinary nature of BCI

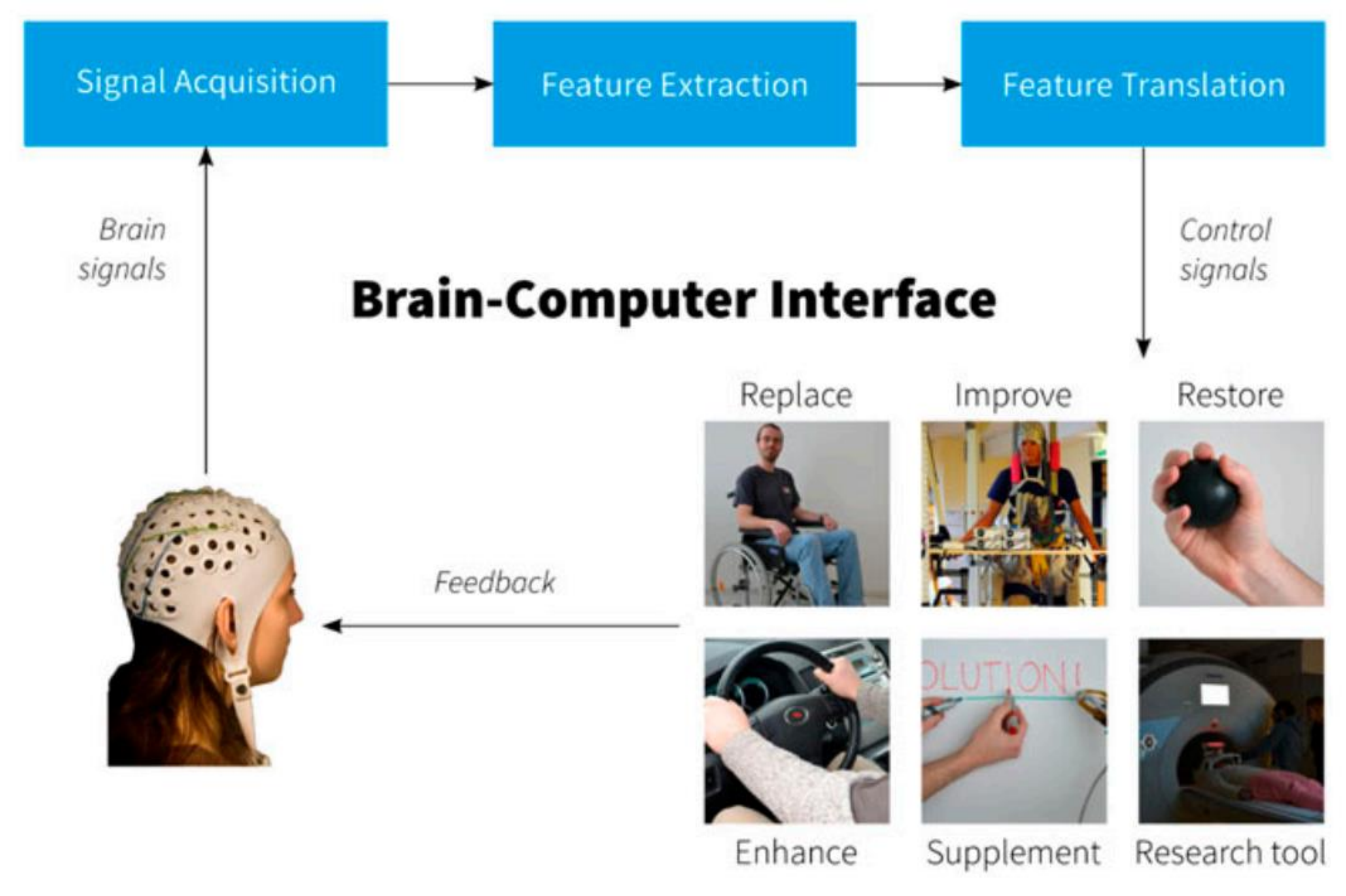


Active, Reactive and Passive BCI

- **Active** BCI systems: brain activity is consciously, intentionally modulated in order to control some application (e.g. motor imagery, relaxation).
- **Reactive** BCI: using brain activity evoked by external stimulation, modulated indirectly through voluntary attention (e.g. P300 amplitudes modulated by attention shifts).
- **Passive** BCI system: automatic, involuntary brain activity (arousal, stress, workload, vigilance, emotions, surprise) is measured and interpreted in a given context, used as input to support an ongoing task.

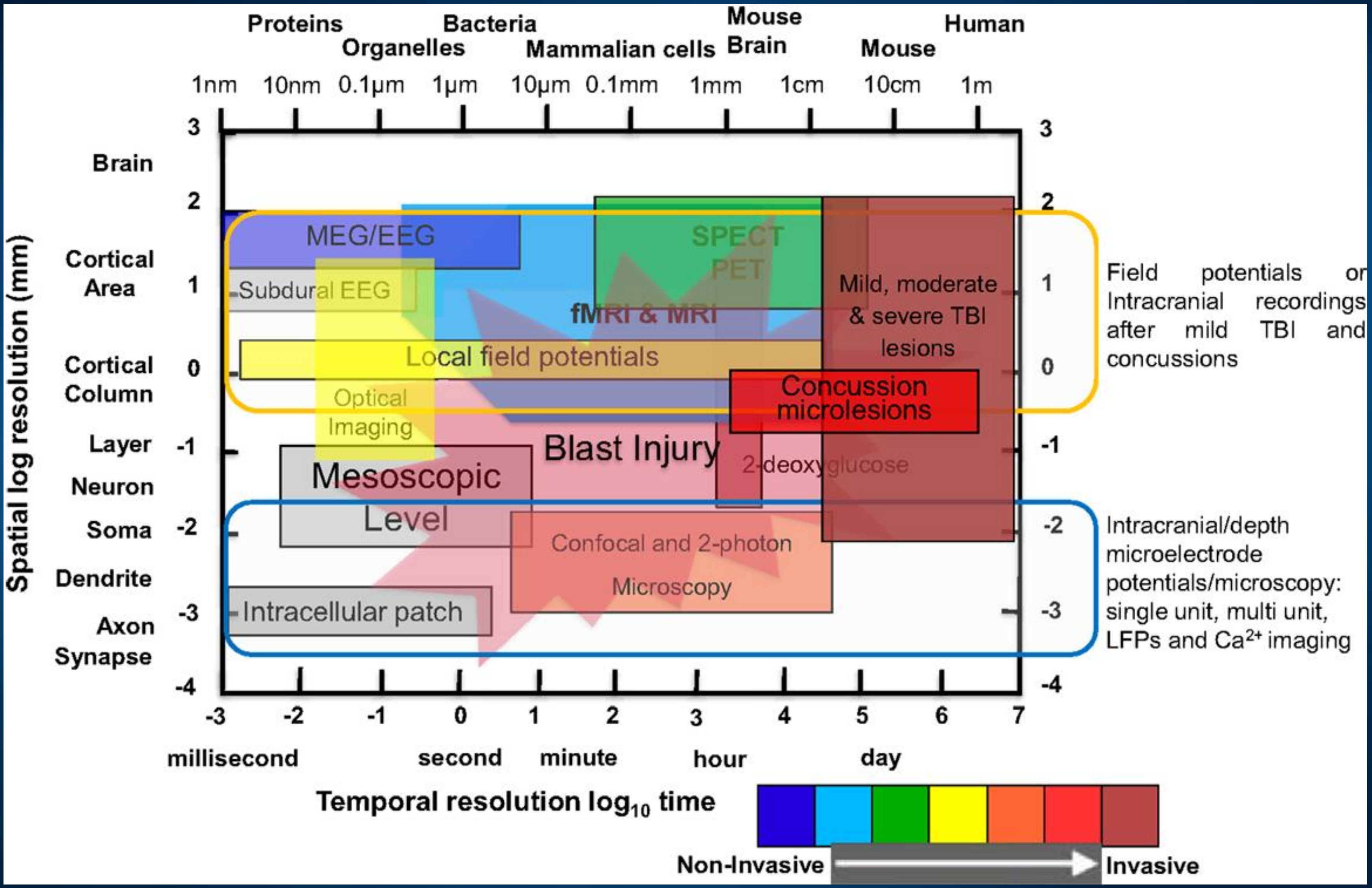
Distinction between active-reactive-passive is sometimes blurred, depends on the user's behavior.

BCI Applications

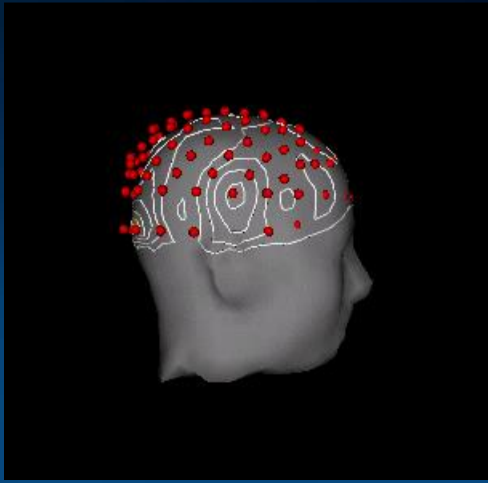


Signals: invasive (brain implants), partially invasive (ECoG), and non-invasive.

Neuroimaging techniques



Passive BCI



Passive BCI uses EEG signal arising in automatic, non-intentional way, in combination with other signals.

Tracking eye movements to control technical systems is used in many applications. Directing a cursor in HCI is gaining popularity for both healthy and disabled users alike.

We use it for infant research, and for computer control by DOC patients.

Dwell-times may incorrectly interpret accidental fixations, or spontaneous dwellings as a user command – this is called “Midas touch” effect.

Event-related potentials (ERPs) might indicate a user’s intention to select. Negativity over parietal electrodes for the intention of item selection gave an average accuracy of 81%.

The intention to interact evokes specific brain activity that can be detected by passive EEG-based BCI technology.

- Protzak J, Ihme K, & Zander T.O. (2013). A Passive Brain-Computer Interface for Supporting Gaze-Based Human-Machine Interaction.

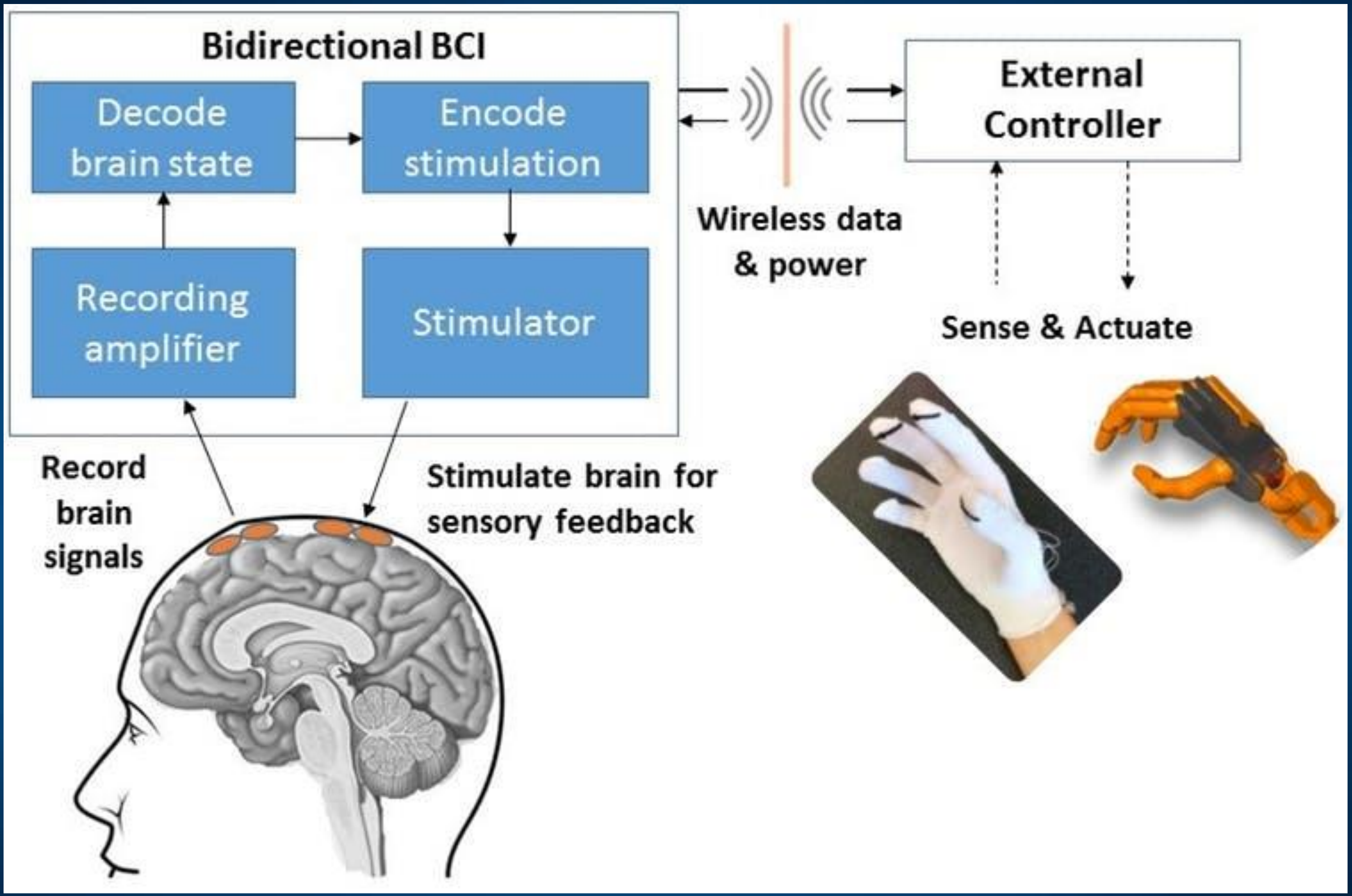
Passive BCI types

pBCI types:

- **mental state assessment**, eg. cognitive workload, neuroergonomics, lie detectors, neuromarketing;
- **open-loop adaptation**, specific brain state => specific action, providing feedback based on mental state assessment, eg. error corrections based on error-related negativity (ERN) overriding human errors;
- **closed-loop adaptation**, specific brain state => mental state assessment => response to state/changes of states => actions that influence mental state.

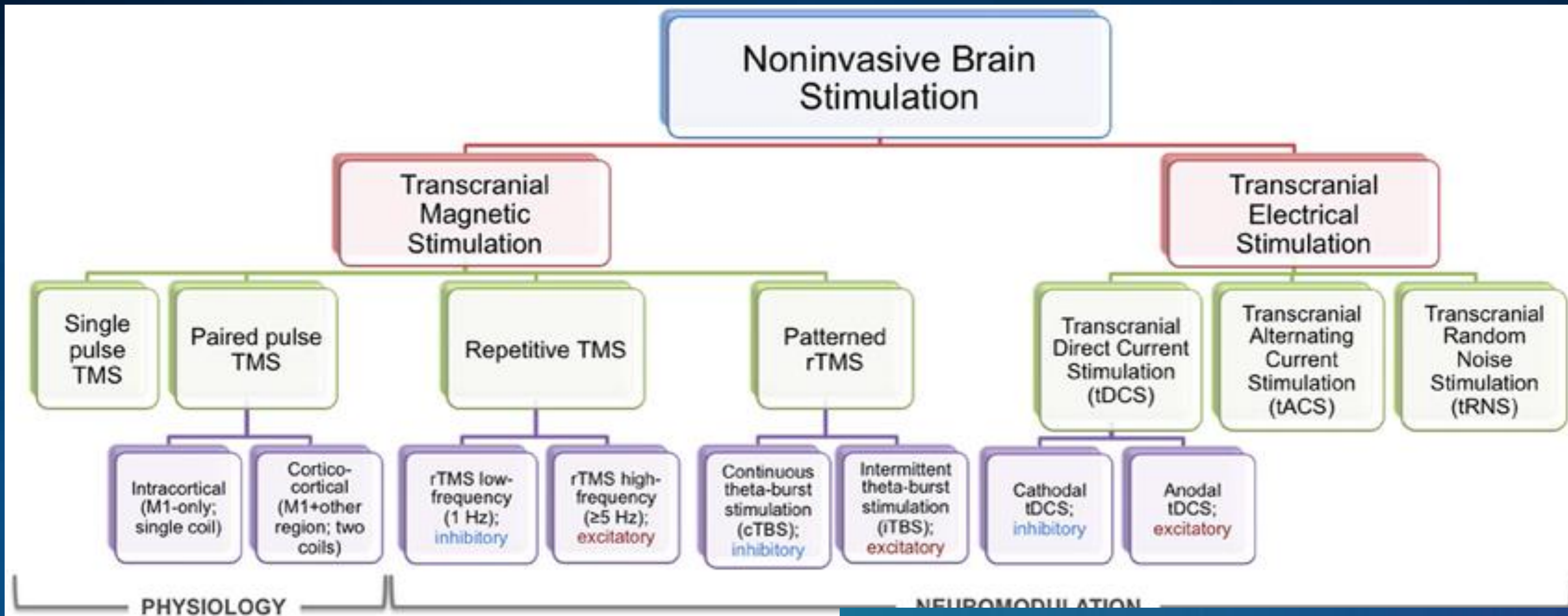
Closed-loop adaptation is especially effective combining BCI with direct brain stimulation (TMS, DCS) enhancing activation of specific brain structures.

Brain-Computer-Brain Interfaces



Closed loop system with brain stimulation for self-regulation.
Body may be replaced by sensory signals in Virtual Reality.

Brain stimulation



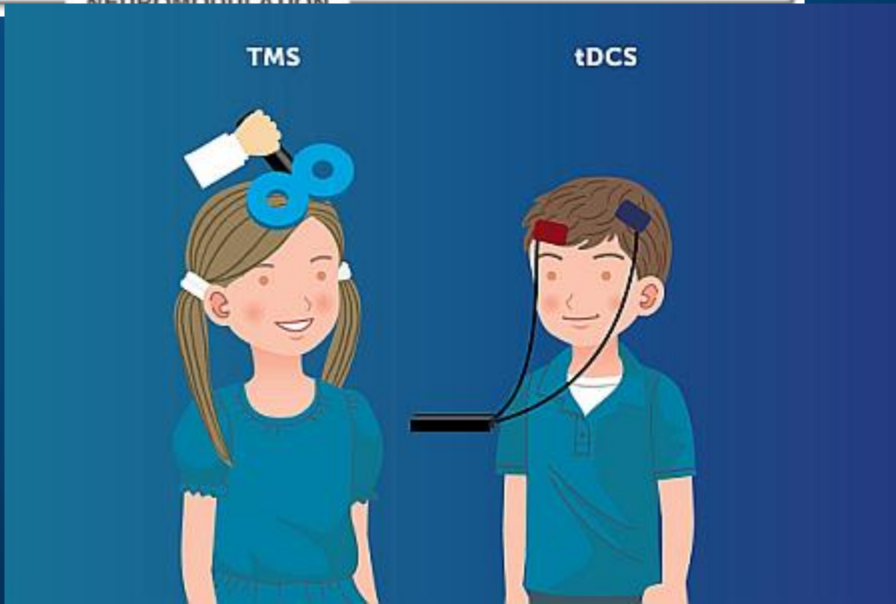
ECT – Electroconvulsive Therapy

VNS – Vagus Nerve Stimulation

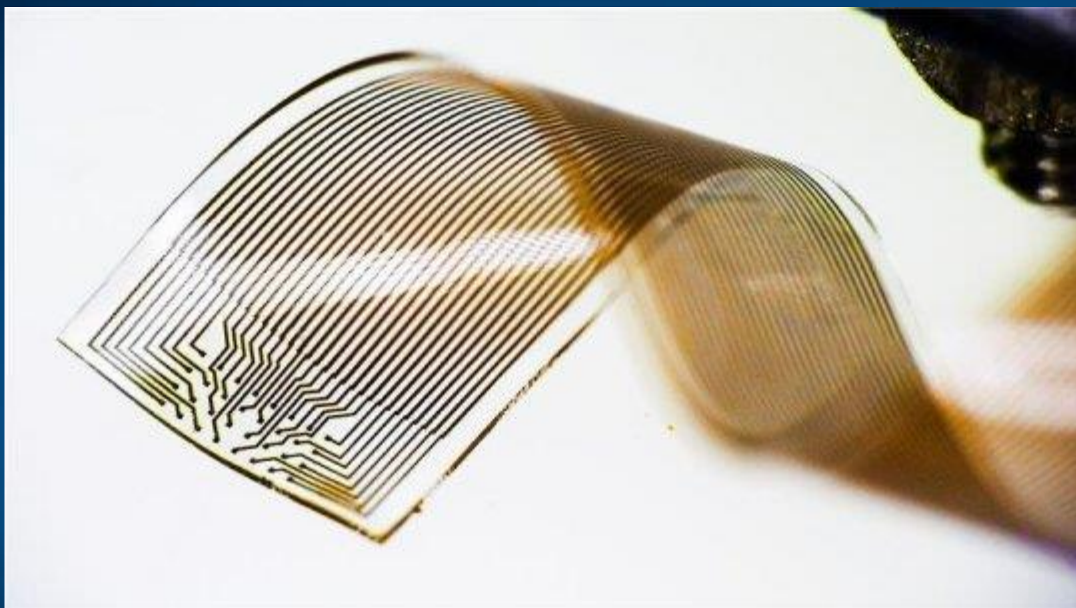
Ultrasound, laser … stimulation.

Complex techniques, but portable phones are also complex.

Attention? Just activate your cortex, no effort is needed!



Partially invasive interfaces

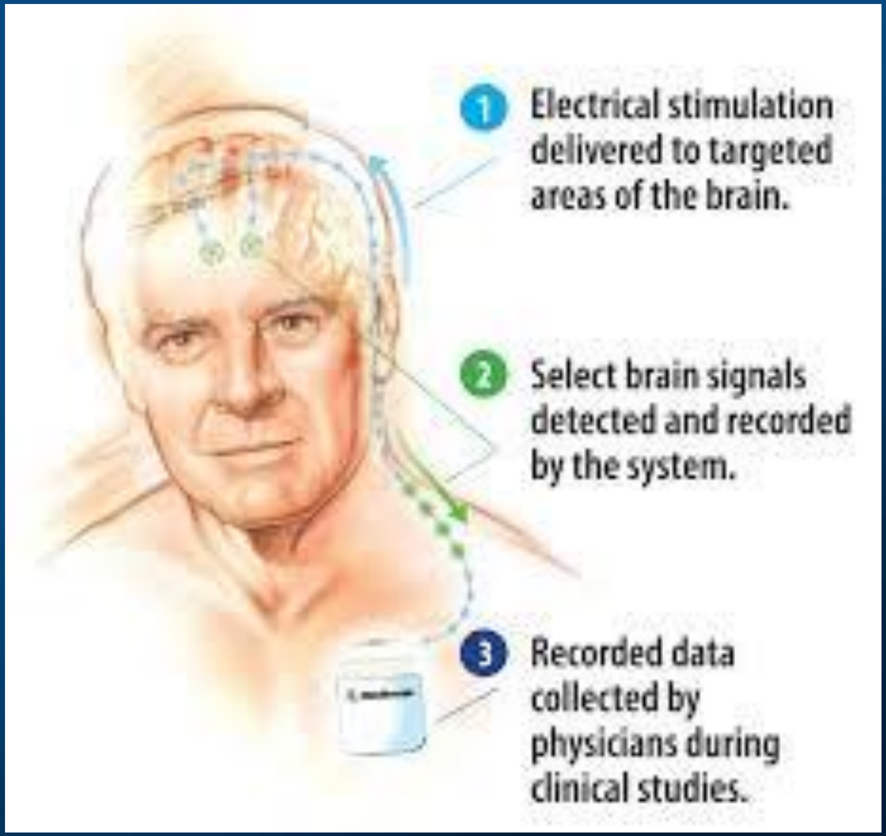


Epilepsy, Obsessive-Compulsive Disorder, Phobias … if you know how to run electric currents through your brain you can control your mental states in a conscious way. New stable electrodes are coming!

Deep brain stimulation

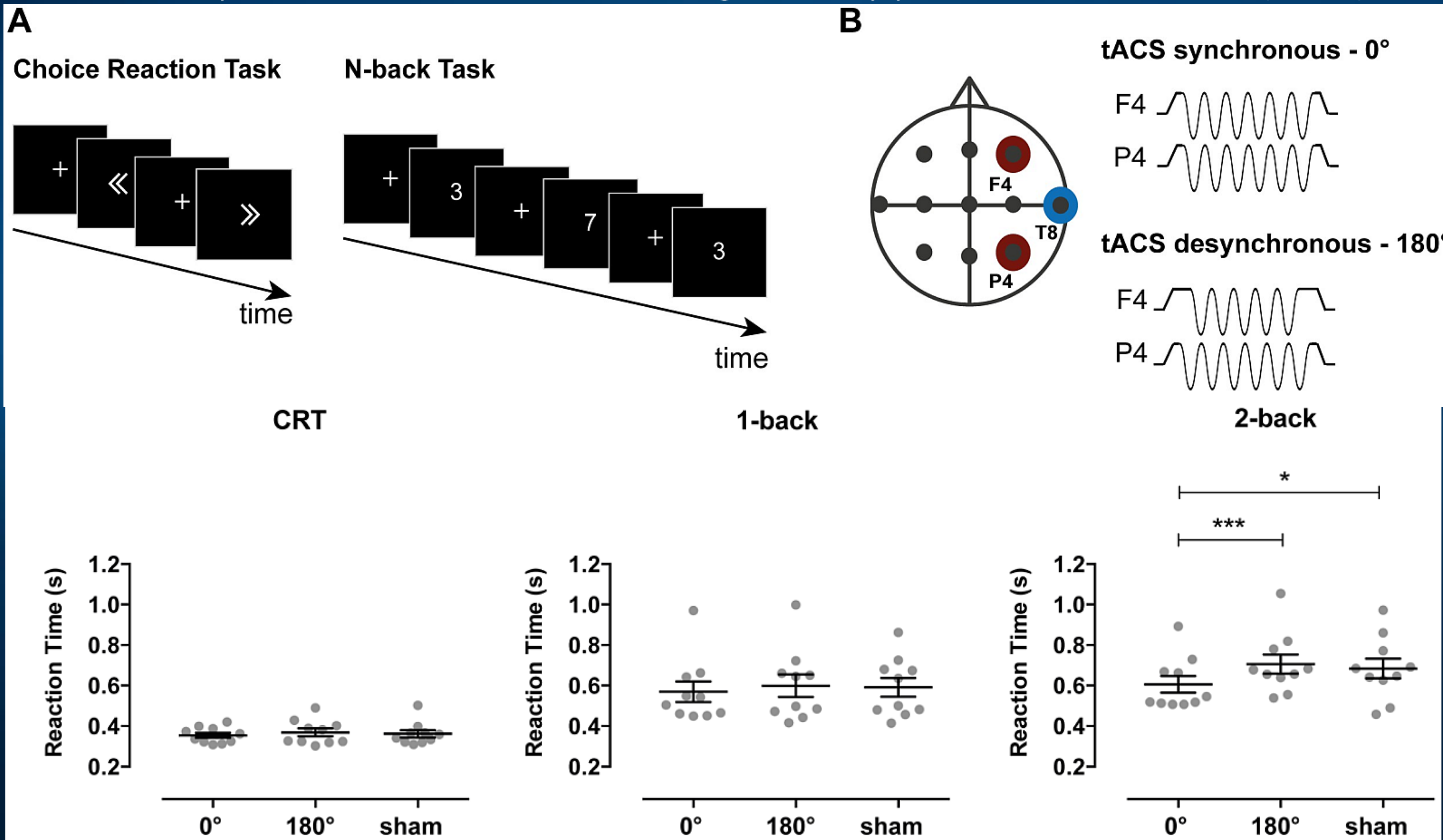
In case of Parkinson's disease, OCD, coma, persistent pain and many other conditions stimulation of peripheral nerves (in particular the vagus nerve), thalamus or certain other parts of the brain using external controller can help. Non-invasive approach using ultrasound interference is possible.

What brain functions can be consciously controlled?



Synchronize PFC/PC

Violante, I.R. et al. Externally induced frontoparietal synchronization modulates network dynamics and enhances working memory performance. ELife, 6 (2017).



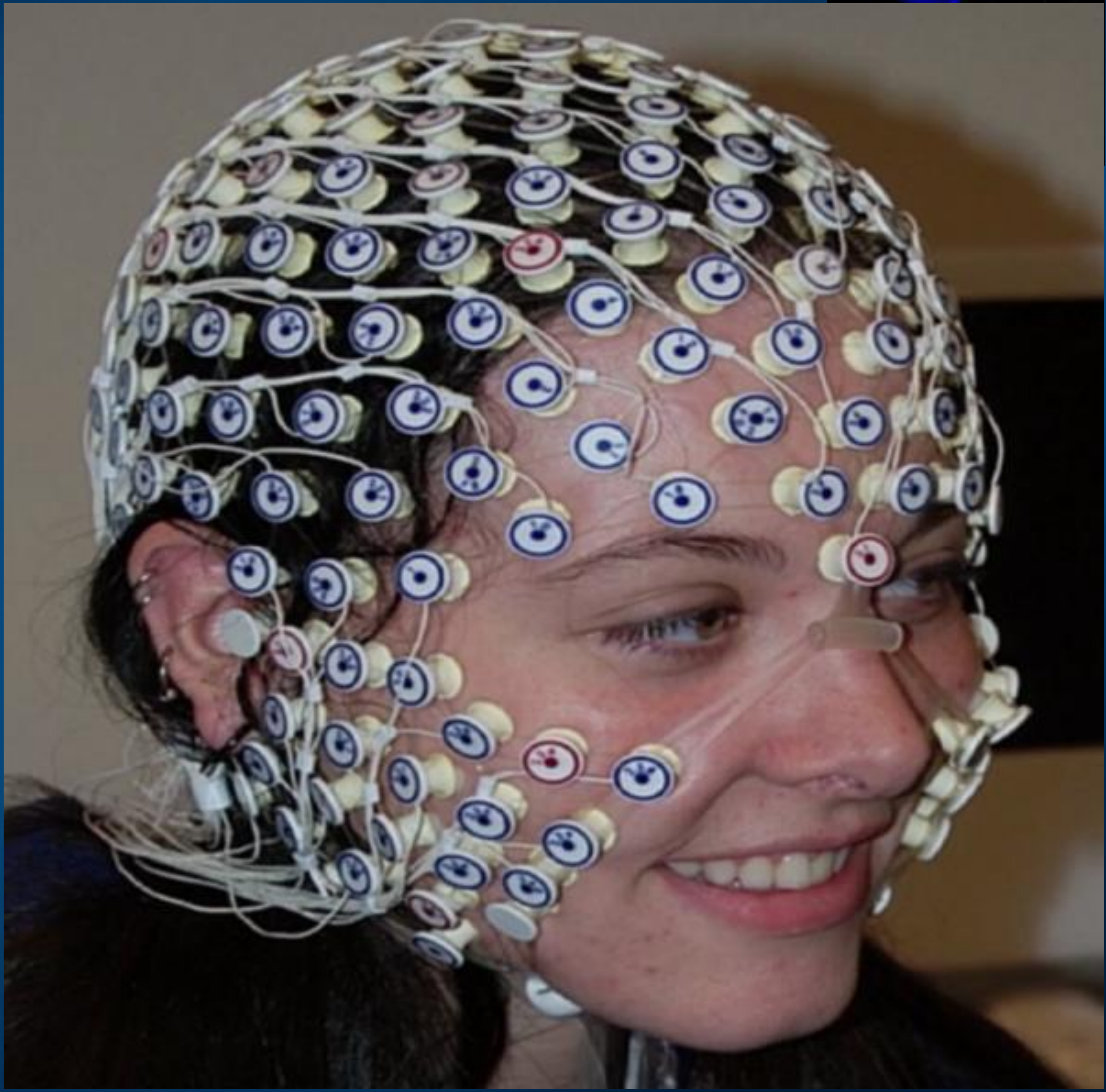
HD EEG/DCS?

EEG electrodes + DCS.

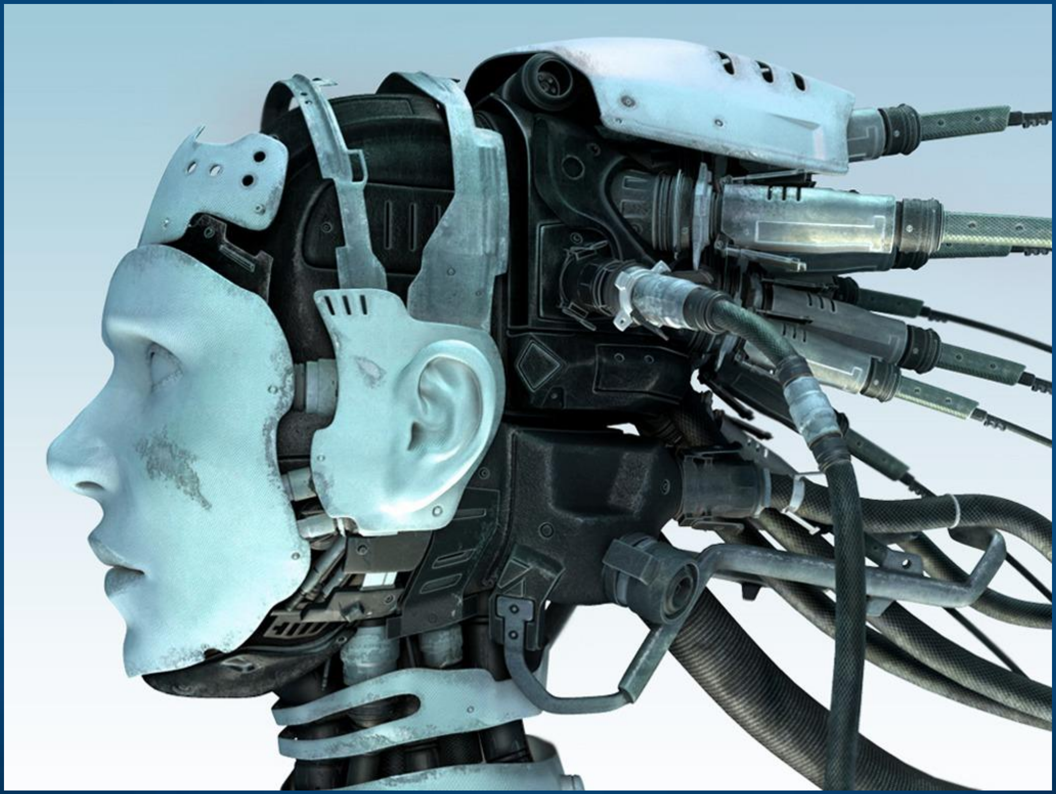
Reading brain states
=> transforming to common space
=> duplicating in other brains …

Depression, neuro-plasticity, pain, psychosomatic disorders, teaching!

Multielectrode DCS stimulation with 256 electrodes induces changes in the brain increasing neuroplasticity.



Neurocognitive technologies

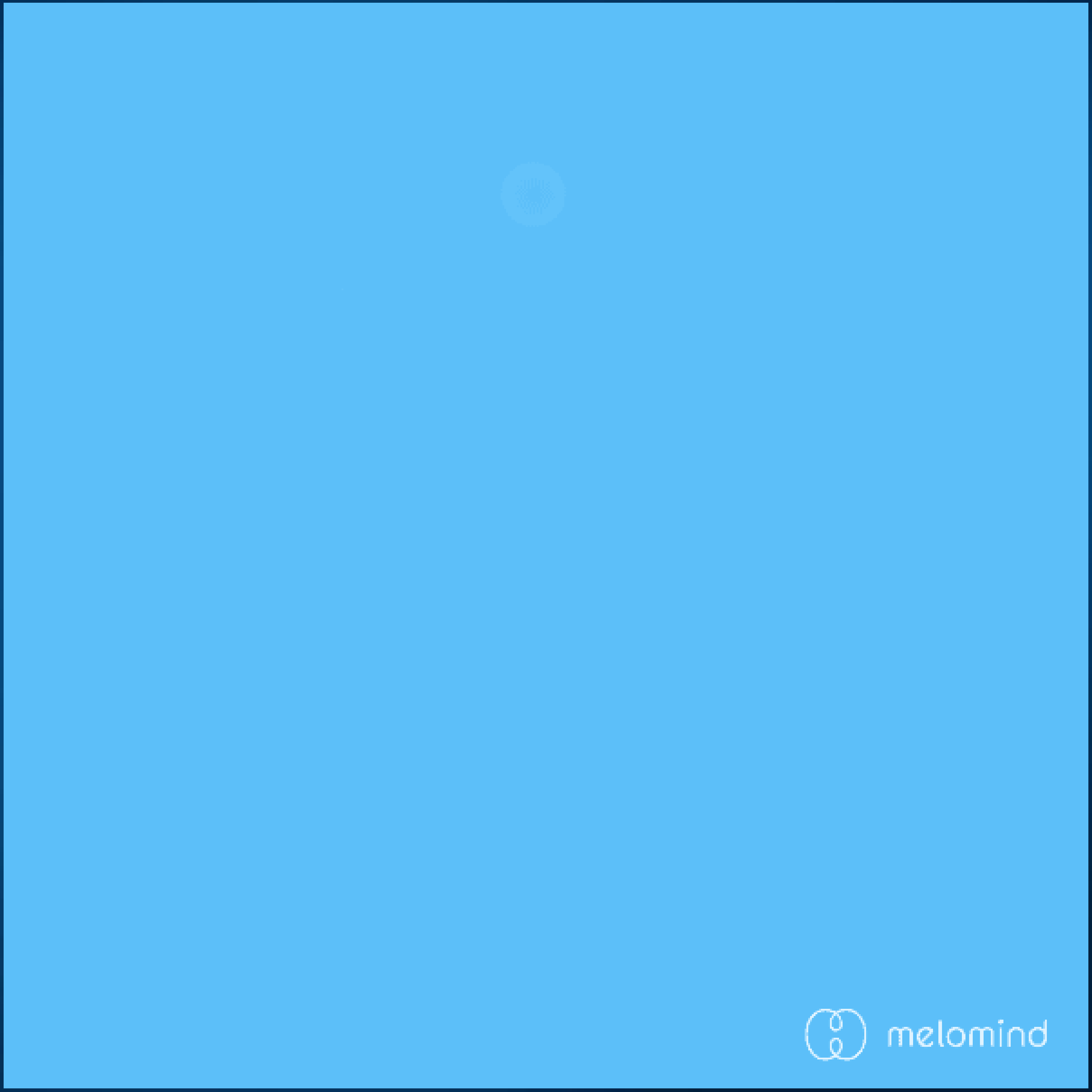


Neuro-relax

Sounds and music may have arousing or relaxing effects.

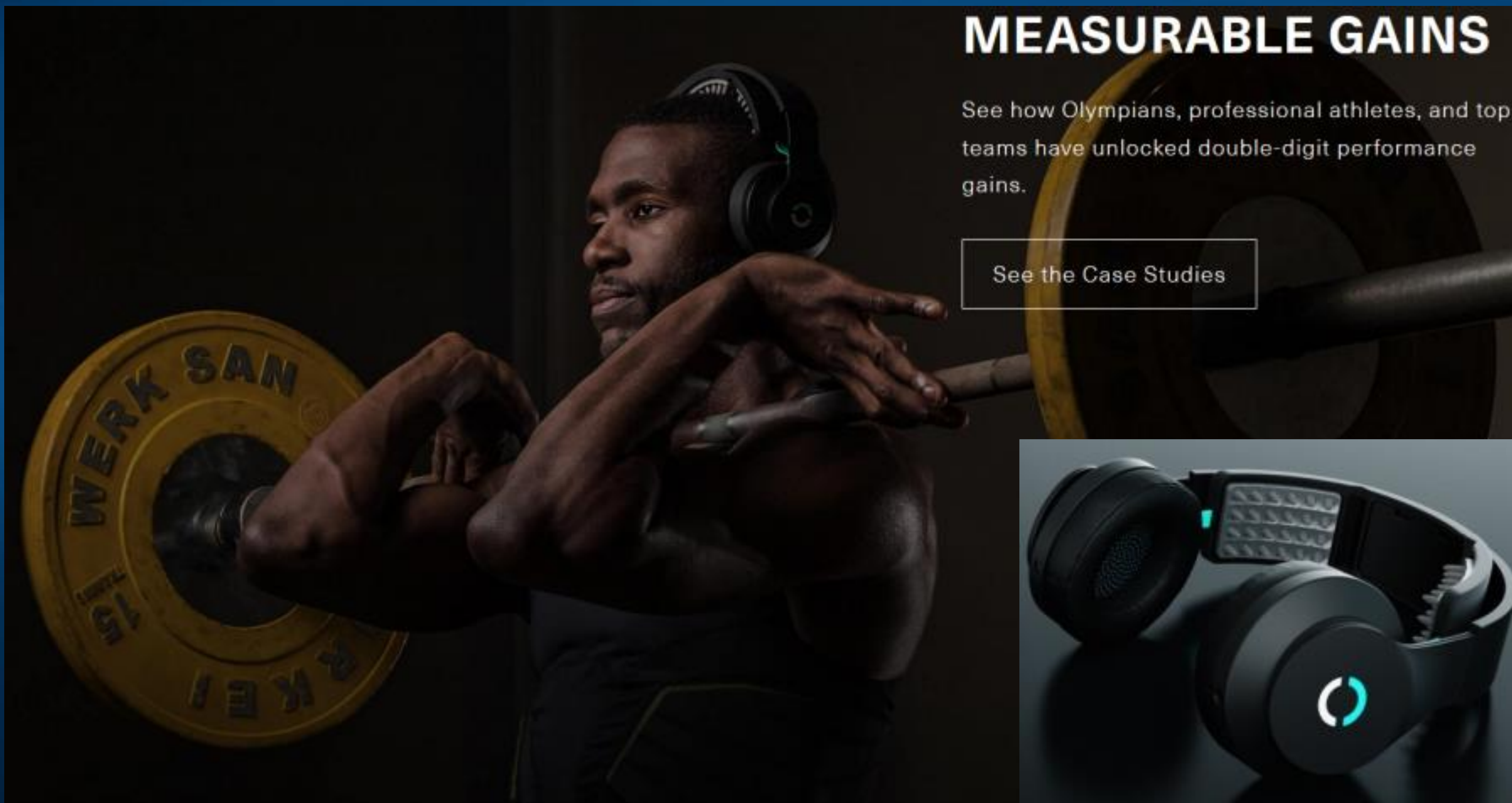
Melomind:

Simple EEG determins the relaxation level and adaptively creates sounds to increase it.



Neuropriming

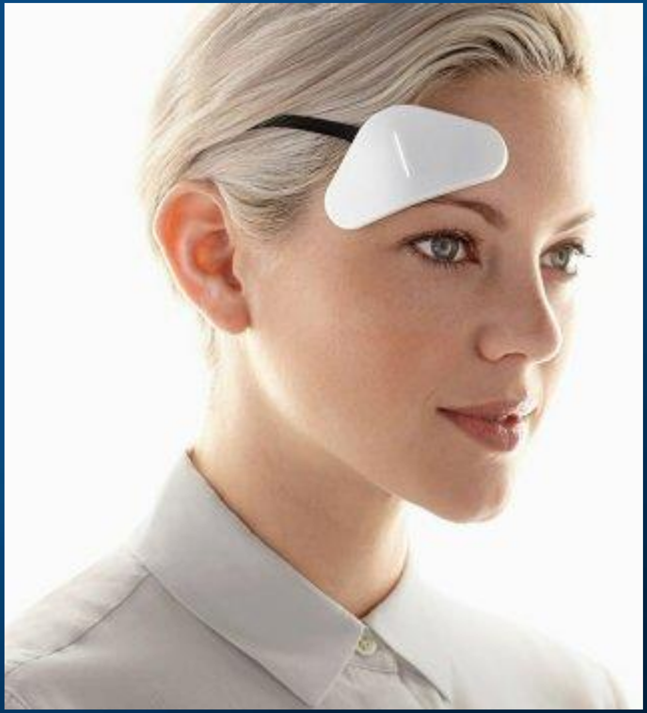
Effort, stamina, force in sports requires strong activation of muscles by motor cortex. Synchronize your effort with direct current cortex stimulation.



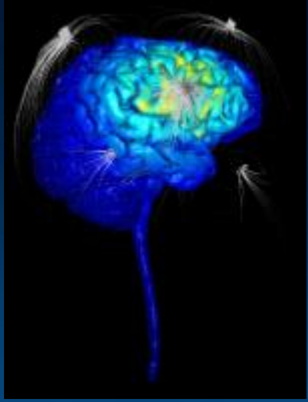
Haloneuro.com

DCS for attention/relaxation

Focusing attention for a long time requires effort: PFC activates brain regions processing signals from various modalities. External stimulation using alternating currents (tDCS) or magnetic pulses (rTMS) gives good results in case of games, pilots, combat soldiers. Control yourself with a smartphone! **Thync** arouses the brain before action and relaxes after.



BCBI for learning



Your brain knows better what is interesting than you do! Information relevance inferred directly from brain signals to model search intent.

Eugster et al. (2016). Natural brain-information interfaces: Recommending information by relevance inferred from human brain signals.

Externally induced frontoparietal synchronization modulates network dynamics and enhances working memory performance (Violante et al. 2017).

Neuroimaging based assessment strategy may provide an objective means of evaluating learning outcomes in the application of **Universal Design for Learning** (UDL), an educational framework created to guide the development of flexible learning environments that adapt to individual learning differences.

Teaching skills by stimulating cortex: microstimulation too low to evoke muscle activation, applied in premotor cortex, instructed specific actions.

- Mazurek & Schieber (2017). Injecting Instructions into Premotor Cortex. *Neuron*, *96*(6), 1282–1289.e4.

Military applications

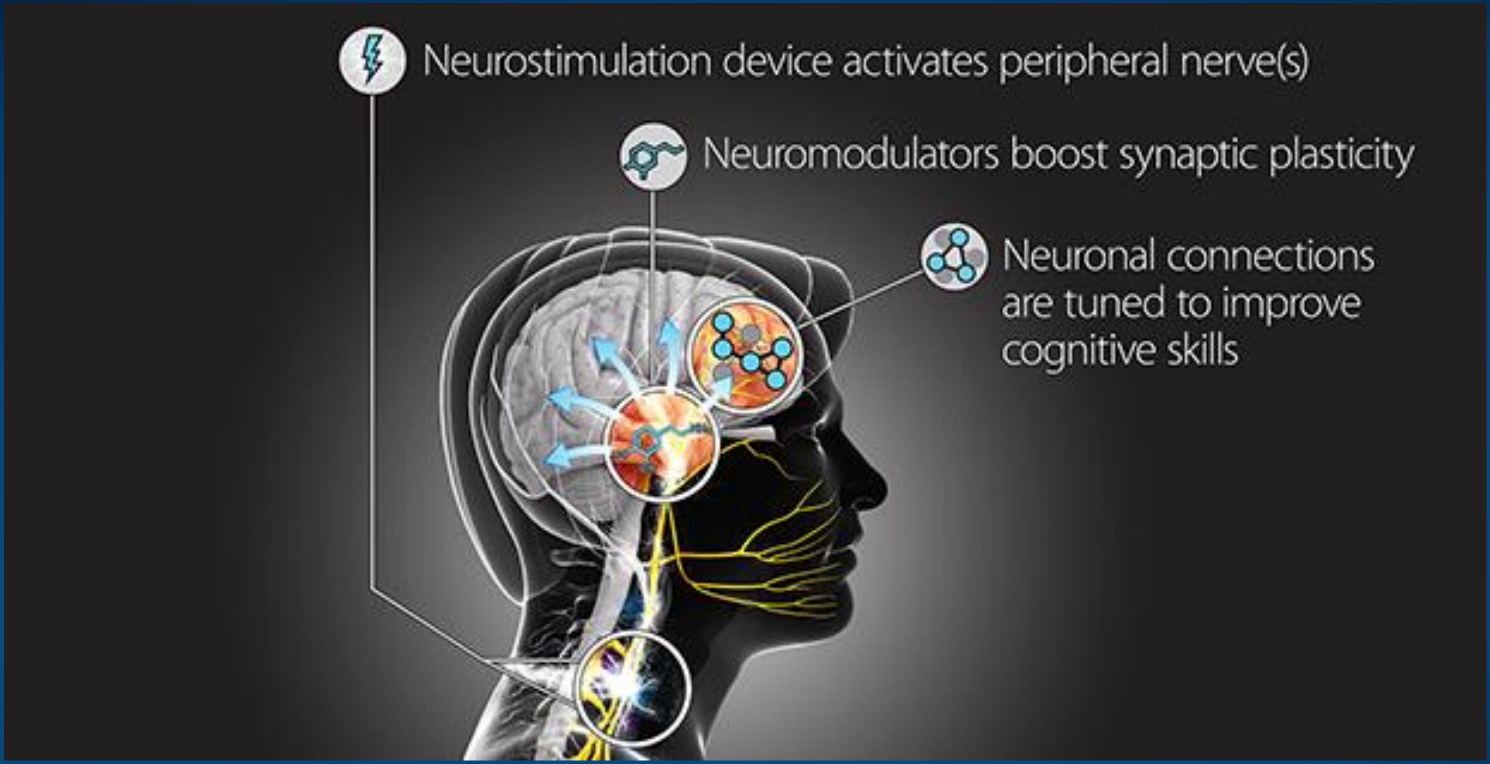
Engagement Skills Trainer (EST) procedures are used by USA army.

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

Real-life transfer learning …

HD-tDCS may have 100 channels.

Targeted Neuroplasticity Training



DARPA (2017): Enhance learning of a wide range of cognitive skills, with a goal of reducing the cost and duration of the Defense Department's extensive training regimen, while improving outcomes. TNT could accelerate learning and reduce the time needed to train foreign language specialists, intelligence analysts, cryptographers, and others.

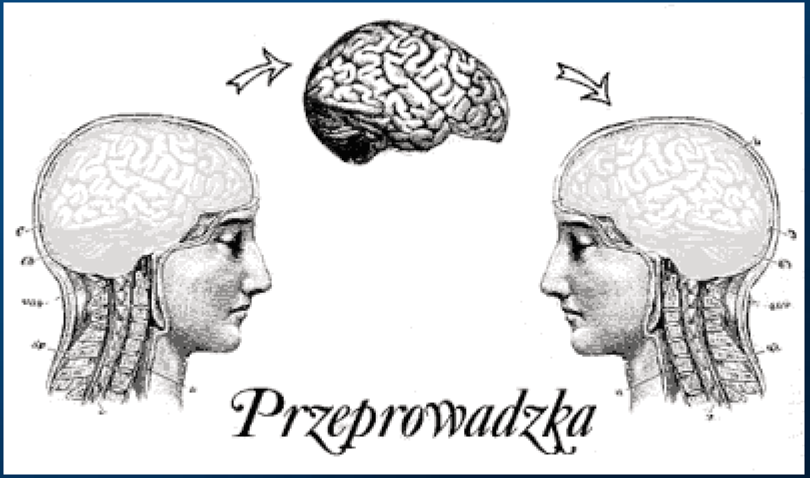
Thought transfer?

EEG + TMS/DCS has been used to transfer simple motor commands using Morse alphabet. Can this technique be more subtle?

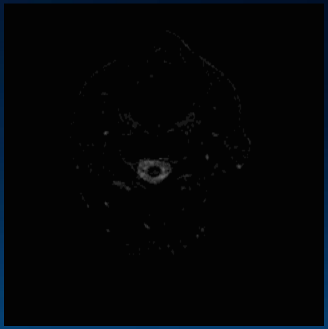
Can this technique be more subtle?

Will mind transfer be possible in future? Long way but remember:

Telegraph => Radio => TV => VR …



Conclusions



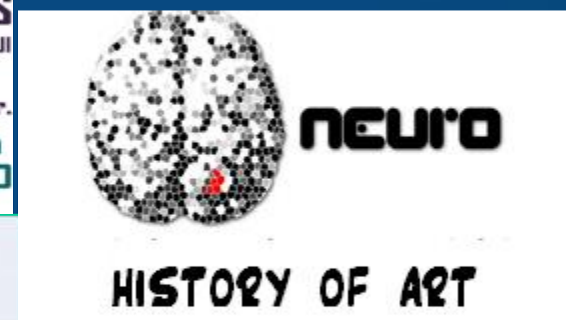
- Optimization of brain processes should be possible, but first we need to find good methods for discovering brain fingerprints of cognitive activity, mapping between brain and mental states – our main goal.
- Brain reading and stimulation, understanding neurodynamics and neurocognitive phenomics, are the key to BCBI for voluntary self-regulation of brain functions, and numerous therapeutic applications.
- Roadmap: Brain neuroimaging ⇔ models of brain processes ⇔ links with mental models ⇔ closed loop BCBI for conscious control/brain optimization
- Neuromorphic hardware with complexity beyond the human brain is coming (ex. IBM Synapse project) and will enable construction of new brain models, deeper understanding of brain functions, and practical applications.
- Neurolace from Neuralink, DARPA project to put million electrodes in human brain and many other developments will integrate brains with artificial systems and change the BCBI game.
  With new global AI initiatives anything is possible!

Soul or brain: what makes us human? Interdisciplinary Workshop with theologians, Toruń 19-21.10.2016

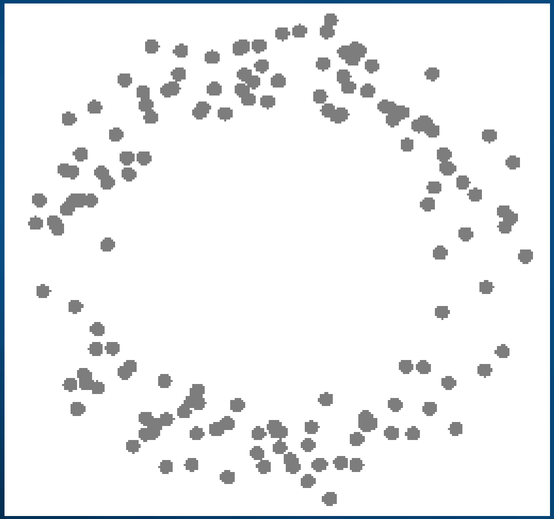
Monthly international developmental seminars (2017): Infants, learning, and cognitive development

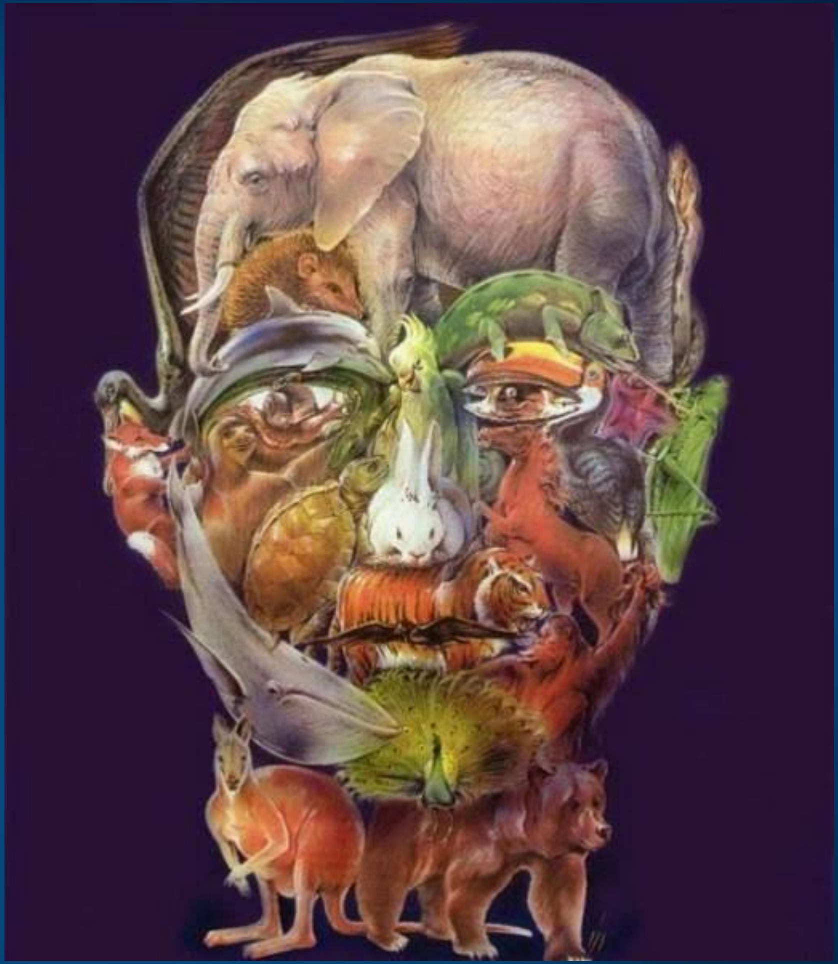
Disorders of consciousness 17-21.09.2017

Autism: science, therapies 23.05.2017



Thank you for synchronization of your neurons





Google: W. Duch

=> talks, papers, lectures, Flipboard …

Brain control paradigm

EU FET Flagship Projects:
Brain and Mind. But Human Brain Project won … it was going to build something like **The Virtual Brain**, that has been developed by 11 labs.

Now we have submitted Sapiens 5.0 to the next EU Flagship: Human-AI collaboration for good (http://www.sapiens5.net/).

Brain network recovery group – Brain NRG.
This group of 17 scientists spanned the domains of computational, cognitive and clinical neuroscience, but shared a focus on understanding brain network dynamics and how it relates to recovery of function.

http://www.brainnrg.org/index.php?section=735