Artificial Intelligence and Neurocognitive Technologies

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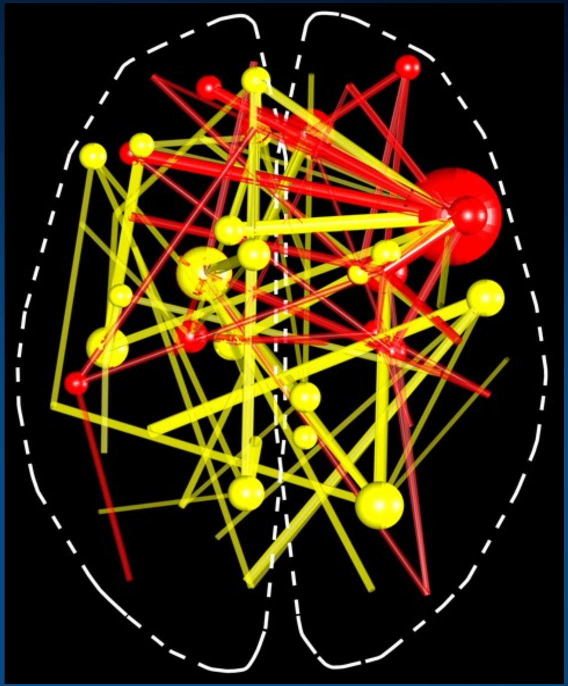
Google: Wlodzislaw Duch

Polsko-Niemieckie Spotkania Naukowe, 14.03.2019

Plan



1. Neurocognitive Laboratory.
2. AI Progress.
3. What next? AI and neuroscience.
4. Global and Emerging Brain Initiatives.
5. Brain networks: space for neurodynamics.
6. Dynamic functional brain networks.
7. Neurocognitive technologies.
8. Perspectives and benefits.

Duch W, *Neurocognitive Informatics Manifesto.* In: Series of Information and Management Sciences, California Polytechnic State Univ. 2009.

REGIONAL PROGRAMME
NATIONAL COHESION STRATEGY

KUJAWSKO-POMORSKIE
VOIVODESHIP

EUROPEAN UNION
EUROPEAN REGIONAL
DEVELOPMENT FUND

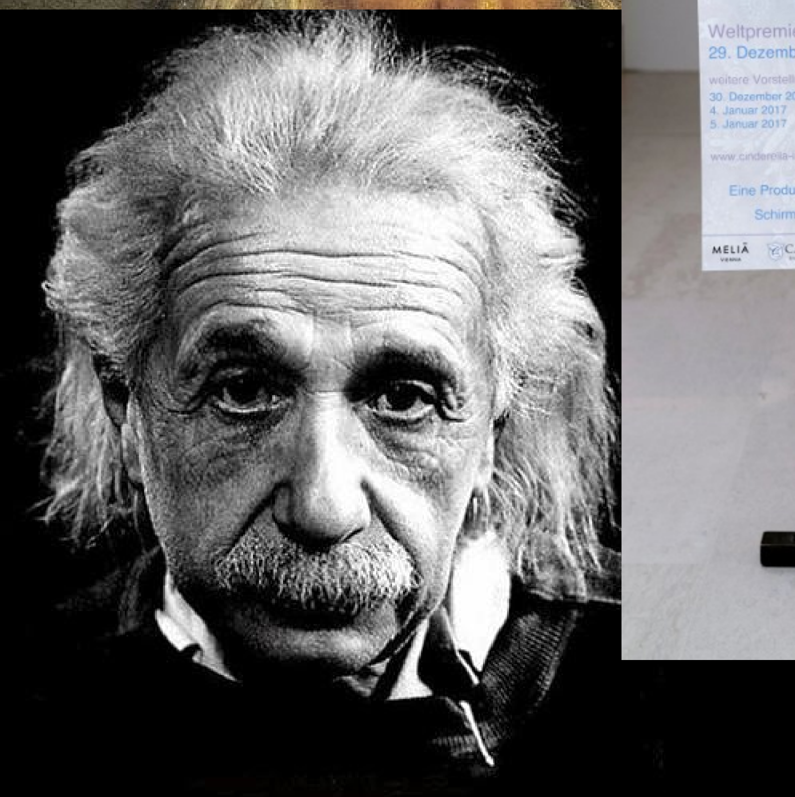
My region in Europe

Neurocognitive Laboratory

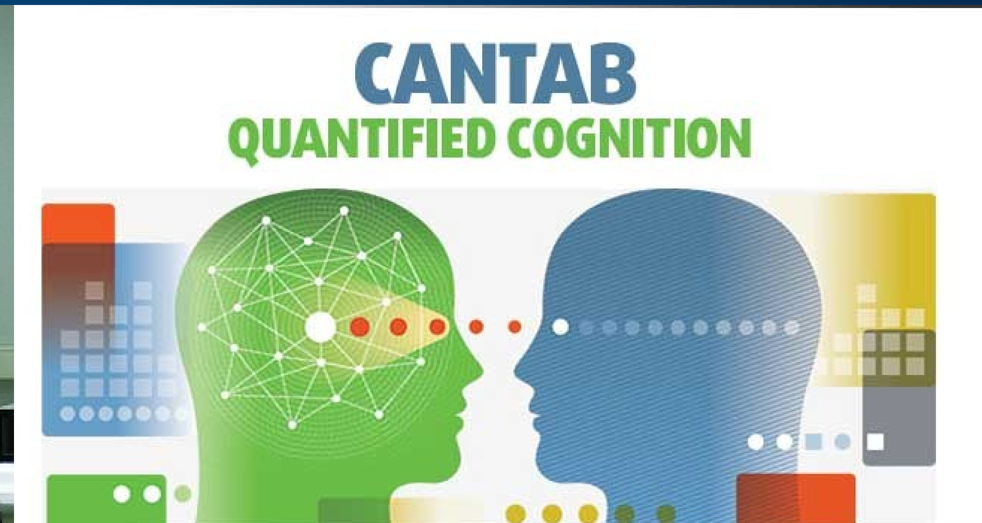
Center for Modern Interdisciplinary Technologies, NCU

Mission: understanding cognitive development, biological basis of behavior, biomarkers of mental problems, relation between minds and brains, and using this knowledge for social innovations that help to develop full human potential during the whole life span.

Do you feel that you have reached optimal brain development?



Our Toys



BabyLab with EEG and Eye-Trackers

Training room

Preparatory room

NARODOWE CENTRUM NAUKI

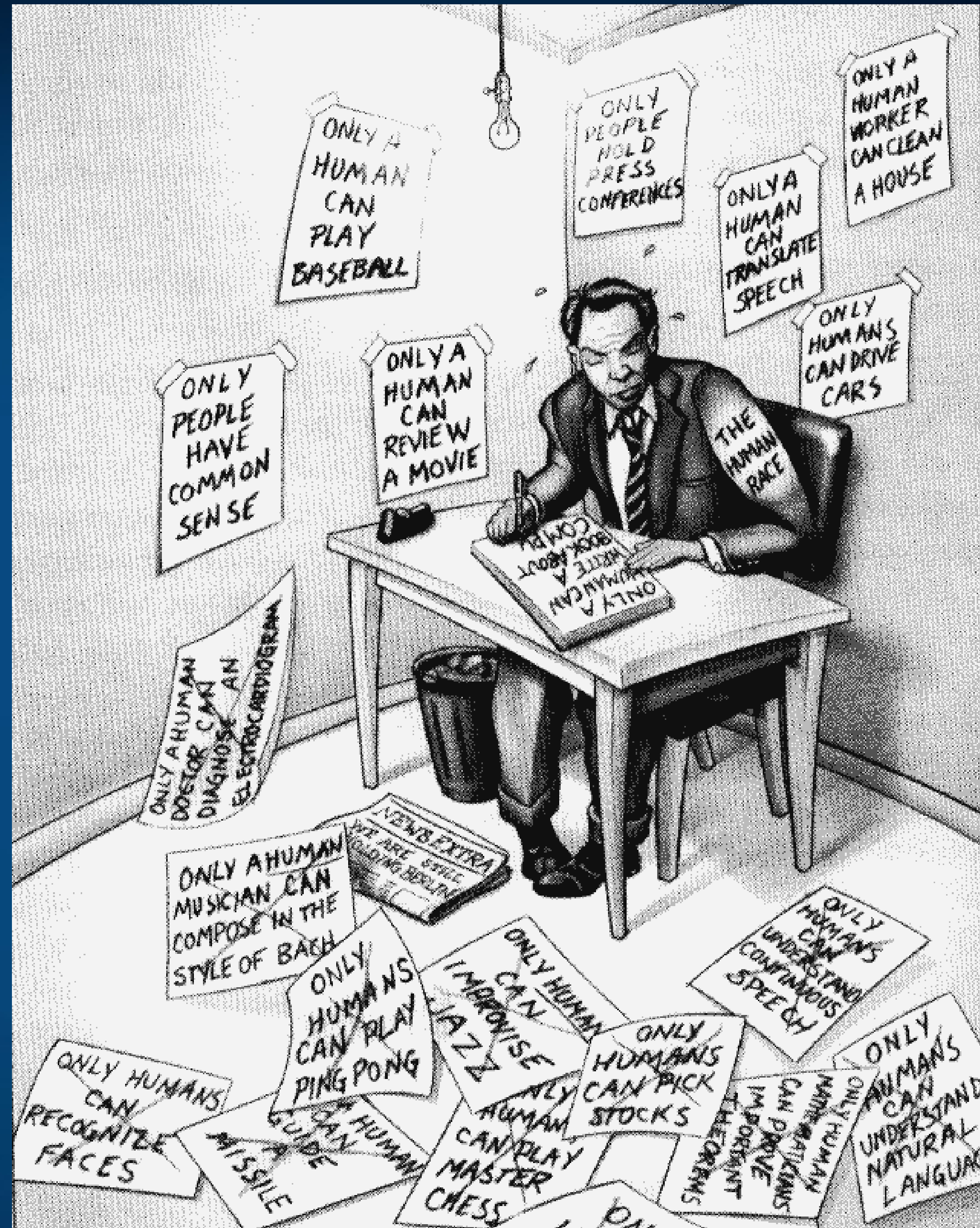
babylab
interdyscyplinarne centrum nowoczesnych technologii

AI Progress

Only humans …

can do things requiring intelligence, but every year this list is getting shorter.

Philosophical critique, ex: H. Dreyfus „What Computers Can't Do" (1972; 1992), „Mind over Machine" (1986), was true but only for the symbolic approach to AI, called now GOFAI.



GOFAI

First wave stumbles

DARPA

2004
completed: 0

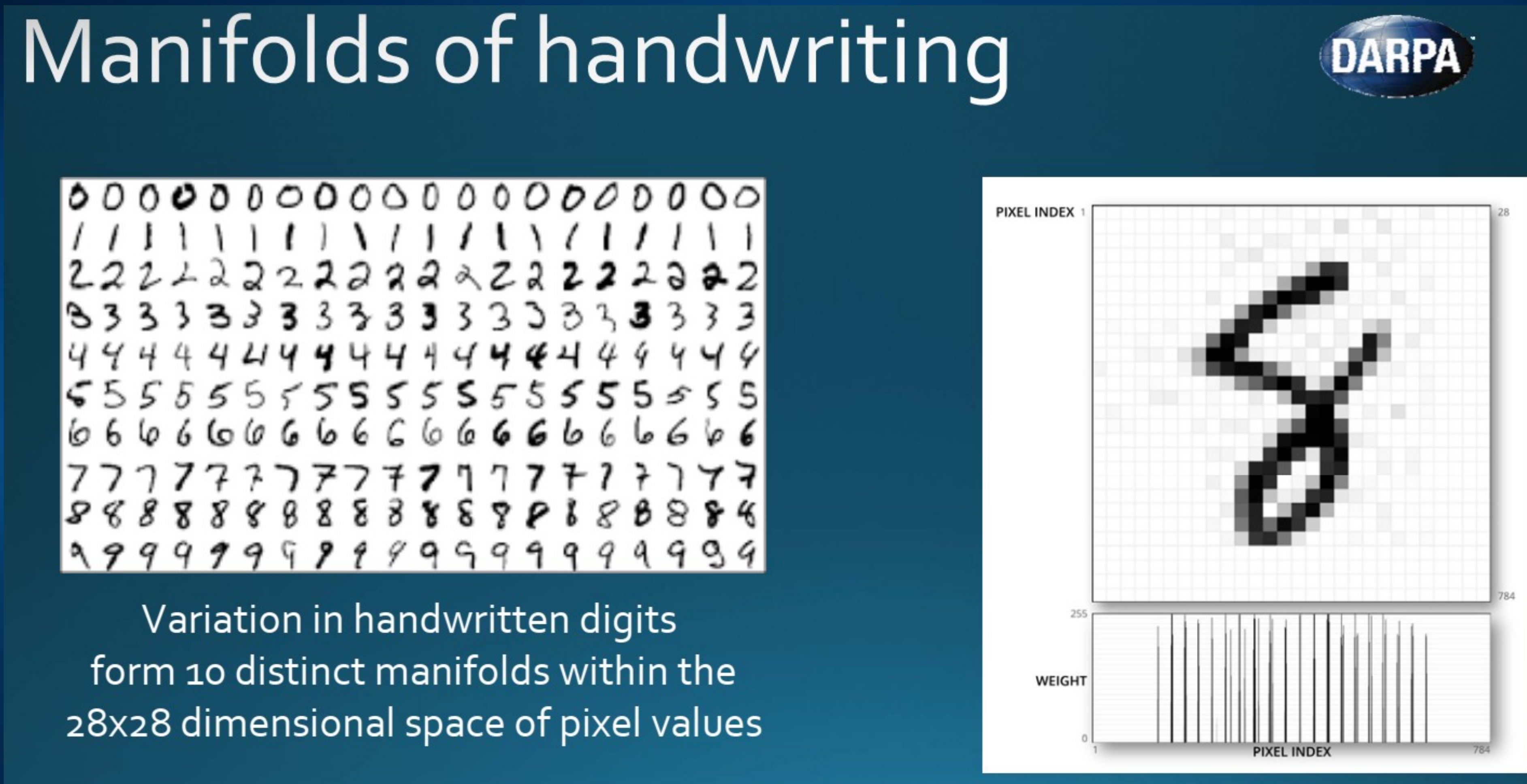
Source: DARPA

2005
completed: 5

DARPA Autonomous Vehicle Grand Challenge
140 miles of dirt tracks in California and Nevada

Perception and control does not work well at symbolic level, so spoon feeding knowledge had to be replaced by machine learning.

Second wave-statistical learning

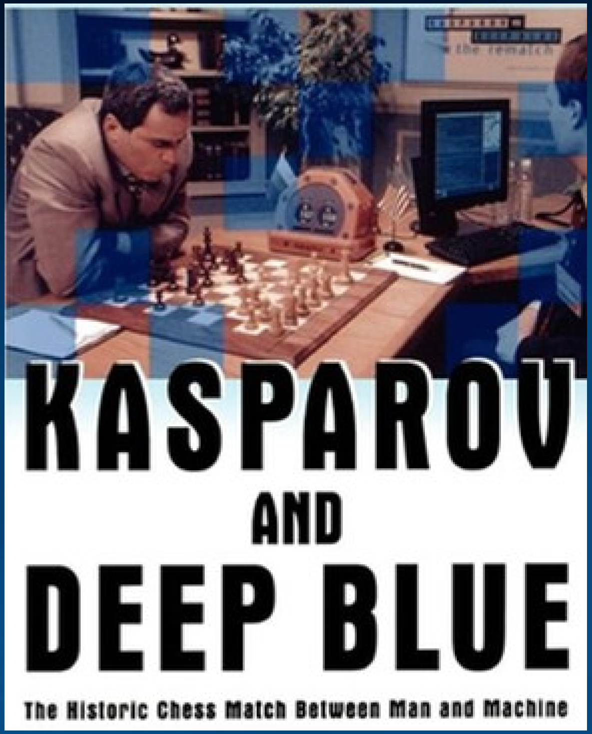


Colelct a lot of data and train classifiers, creating complex data transformation to learn structure of image and signal features.

Power of imitation is great

But no real understanding …

Third AI wave will finally come, not only recognition but building object models and causal models of events.



AI/ML recent milestones

1997 –Deep Blue wins in chess with Kasparov.

2011 – IBM Watson wins in Jeopardy (Va Banque)

2015 – robotic AI controlled lab learns genetic and signaling pathways regeneracji płazińców

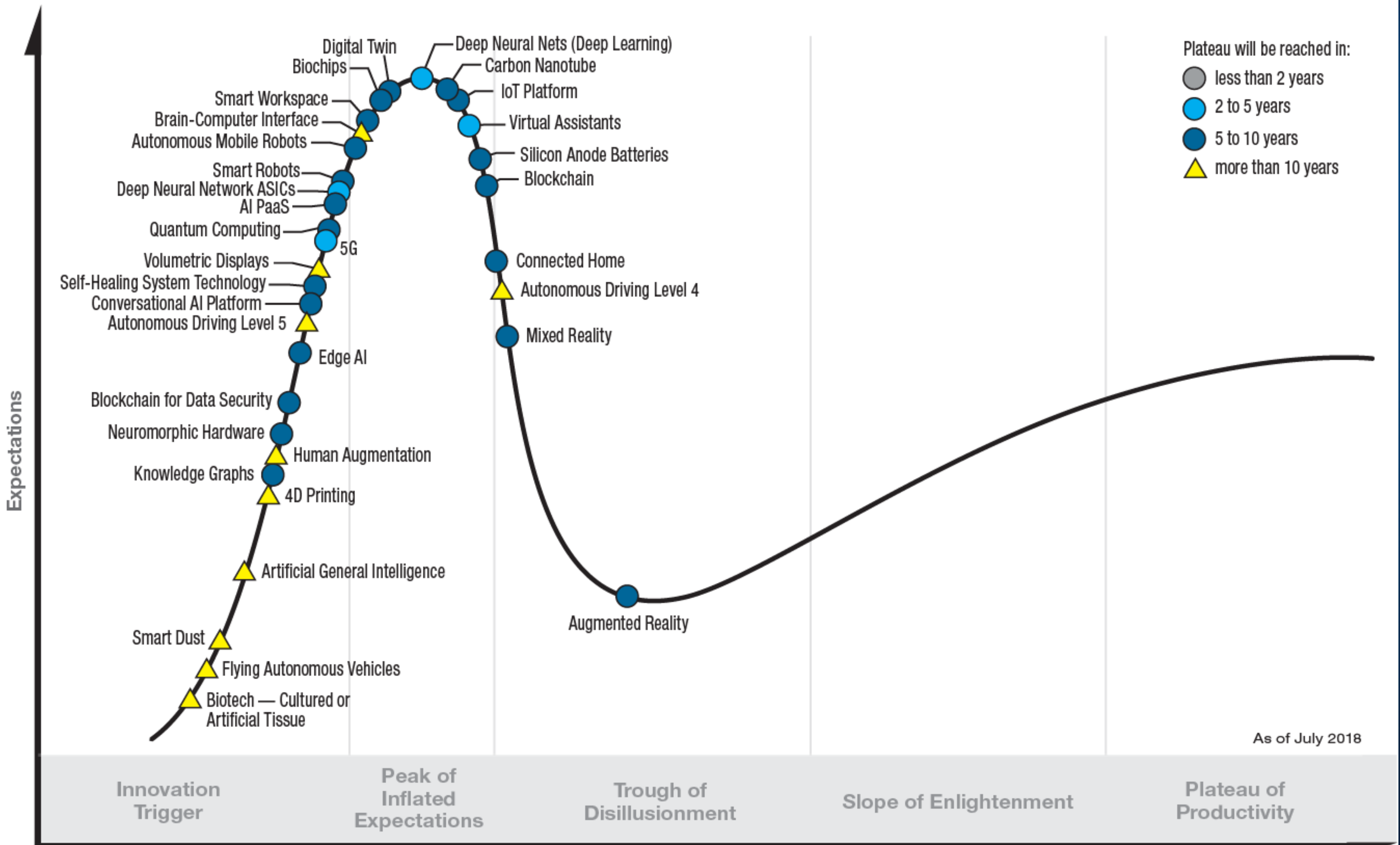
2016 – Google AlphaGo wins with Lee Sedol

2017 – Libratus (CM) wins in poker
OpenAI wins in Dota 2 with professionals.

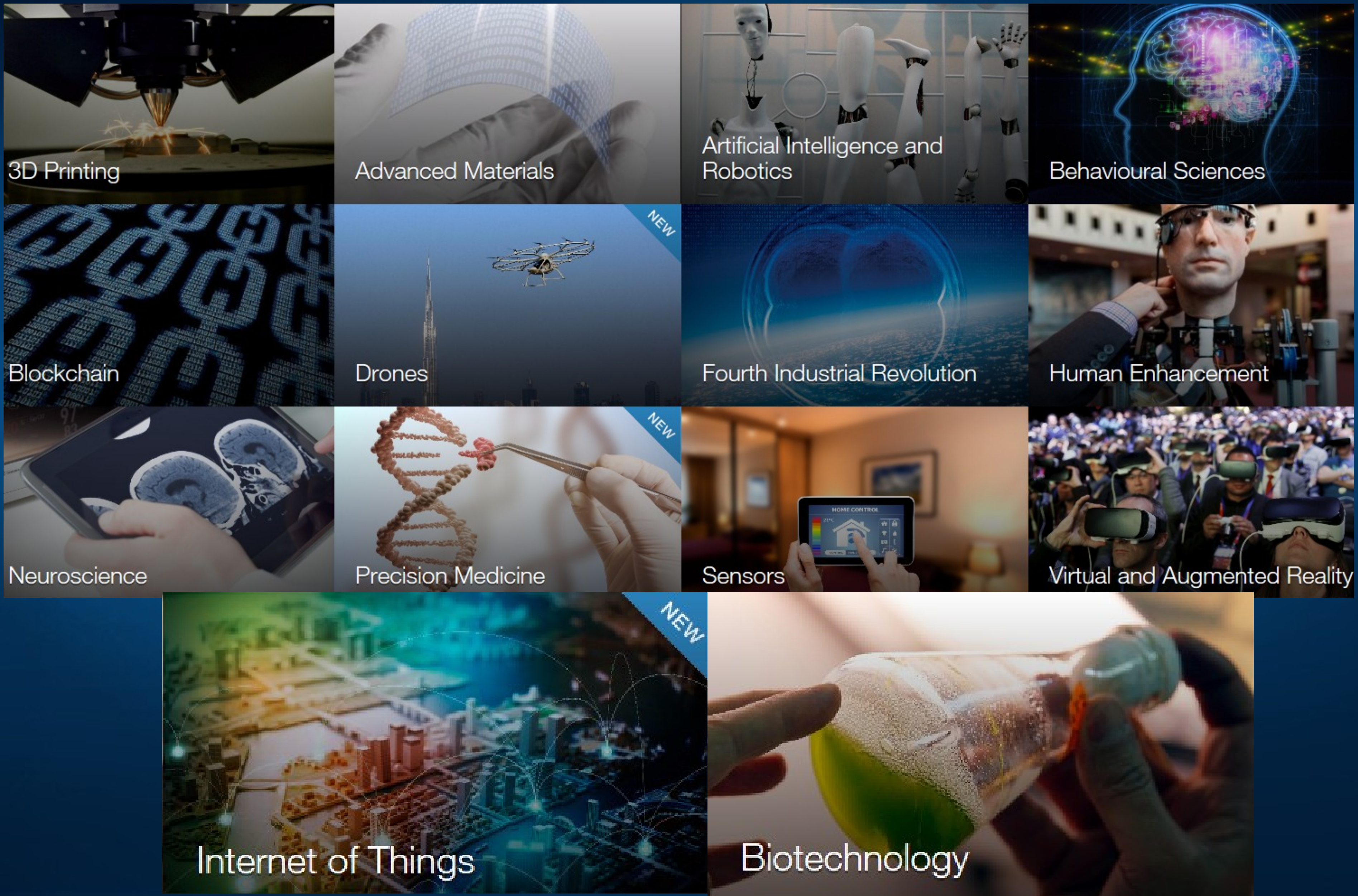
2018 – Watson Debater argues better than humans

2019 – AlphaStar wins 5:0 with StarCraft2 players

Hype Cycle for Emerging Technologies, 2018



Global Transformation: 4th Industrial Revolution, WEF



EU steps in

April 2018: Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee & the Committee of Regions on Artificial Intelligence for Europe.

“Like the steam engine or electricity in the past, AI is transforming our world, our society and our industry. … The economic impact of the automation of knowledge work, robots and self-driving vehicles could reach between EUR 6.5 and EUR 12 trillion annually by 2025.”

By the end of 2018 EU private investments ~3 G€, USA 12-18 G€.
EU as a whole … at least 20 G€ by the end of 2020, then aim for > 20 G€/y.

- Digital Transformation 2021-27 includes:
  supercomputing (2.7 G€)+ AI (2.5 G€) + cybersecurity (2.0 G€) + advanced digital skills/use (700 M€).
- EurAI CLAIR (~2000 wspierających), 7.09 sympozjum.
  ELLIS, European Lab for Learning & Intelligent Systems
- **Coordinated Plan on Artificial Intelligence** 12/2018
  Suddenly AI has embraced machine learning …

What next?
AI and neuroscience.

Neuroscience => AI

Hassabis, D., Kumaran, D., Summerfield, C., Botvinick, M. (2017). Neuroscience-Inspired Artificial Intelligence. *Neuron*, *95*(2), 245–258.

Affiliations: Google DeepMind, Gatsby Computational Neuroscience, Institute of Cognitive Neuroscience, Uni. College London, Uni. of Oxford.

Artificial neural networks – simple inspirations, but led to many applications.

Bengio, Y. (2017). The **Consciousness Prior**. *ArXiv:1709.08568.*

Amoset al. (2018). **Learning Awareness Models**. *ArXiv:1804.06318*.

AI Systems inspired by Neural Models of Behavior:
(A) **Visual attention**, foveal locations for multiresolution ‘‘retinal’’ representation, prediction of next location to attend to.
(B) **Complementary learning systems** and episodic control: fast learning hippocampal system and parametric slow-learning neocortical system.
(C) Models of **working memory** and the Neural Turing Machine.

(D) Neurobiological models of **synaptic consolidation** and the elastic weight consolidation (EWC) algorithm.

Cogni
Cognitive sciences

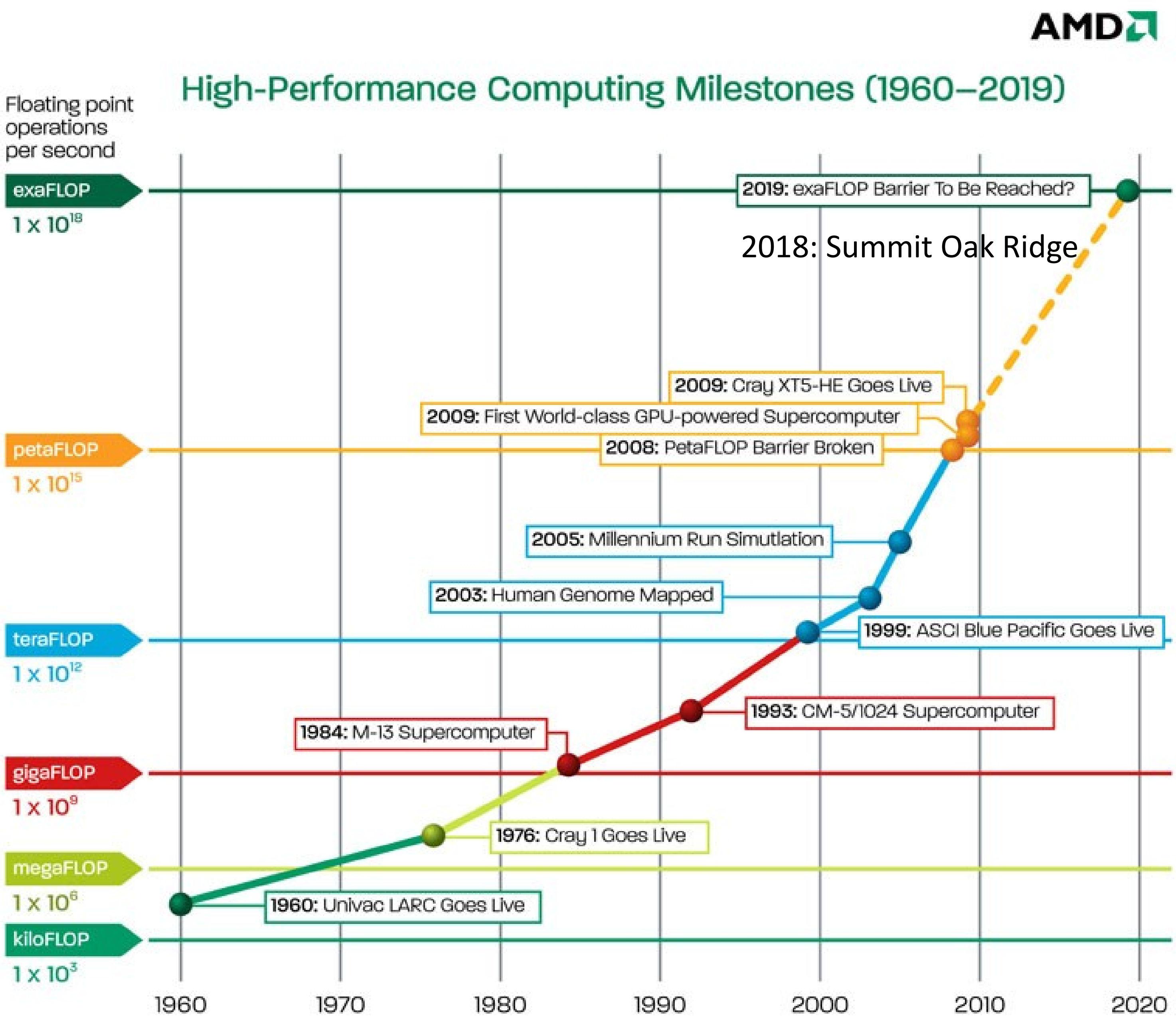
Biohybrids

Bio
Neuroscience

Nano
Quantum Technologies

Neurocognitive Informatics

Info
Artificial/Computational Intelligence, Machine Learning, Neural Networks



AMD
High-Performance Computing Milestones (1960–2019)
Floating point operations per second
exaFLOP
1 x 10^18
petaFLOP
1 x 10^15
teraFLOP
1 x 10^12
gigaFLOP
1 x 10^9
megaFLOP
1 x 10^6
kiloFLOP
1 x 10^3
2019: exaFLOP Barrier To Be Reached?
2018: Summit Oak Ridge
2009: Cray XT5-HE Goes Live
2009: First World-class GPU-powered Supercomputer
2008: PetaFLOP Barrier Broken
2005: Millennium Run Simutlation
2003: Human Genome Mapped
1999: ASCI Blue Pacific Goes Live
1993: CM-5/1024 Supercomputer
1984: M-13 Supercomputer
1976: Cray 1 Goes Live
1960: Univac LARC Goes Live
1960
1970
1980
1990
2000
2010
2020

IBM TrueNorth

- SyNAPSE project created IBM TrueNorth chip in 2015.
  1 chip ~1 M neurons, 1/4 G synapses (5.4 G transistors),
  1 module=16 chips ~16 M neurons, 4 G synapses, power 1.1 wat!
  256 modules ~4 G neurons, 1 T = 10^{12} synapses, power < 300 W.

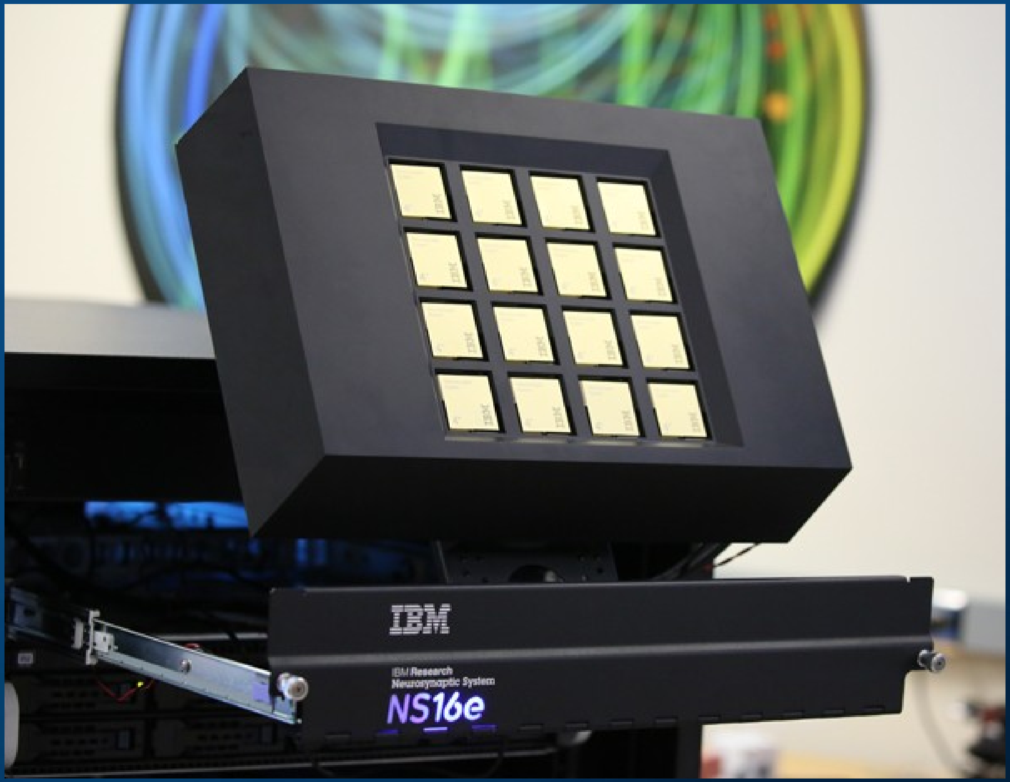
IBM Neuromorphic System
≈ brain complexity.

Not easy to program.

Dynamic Vision Sensor + TN
for fast gesture recognition.

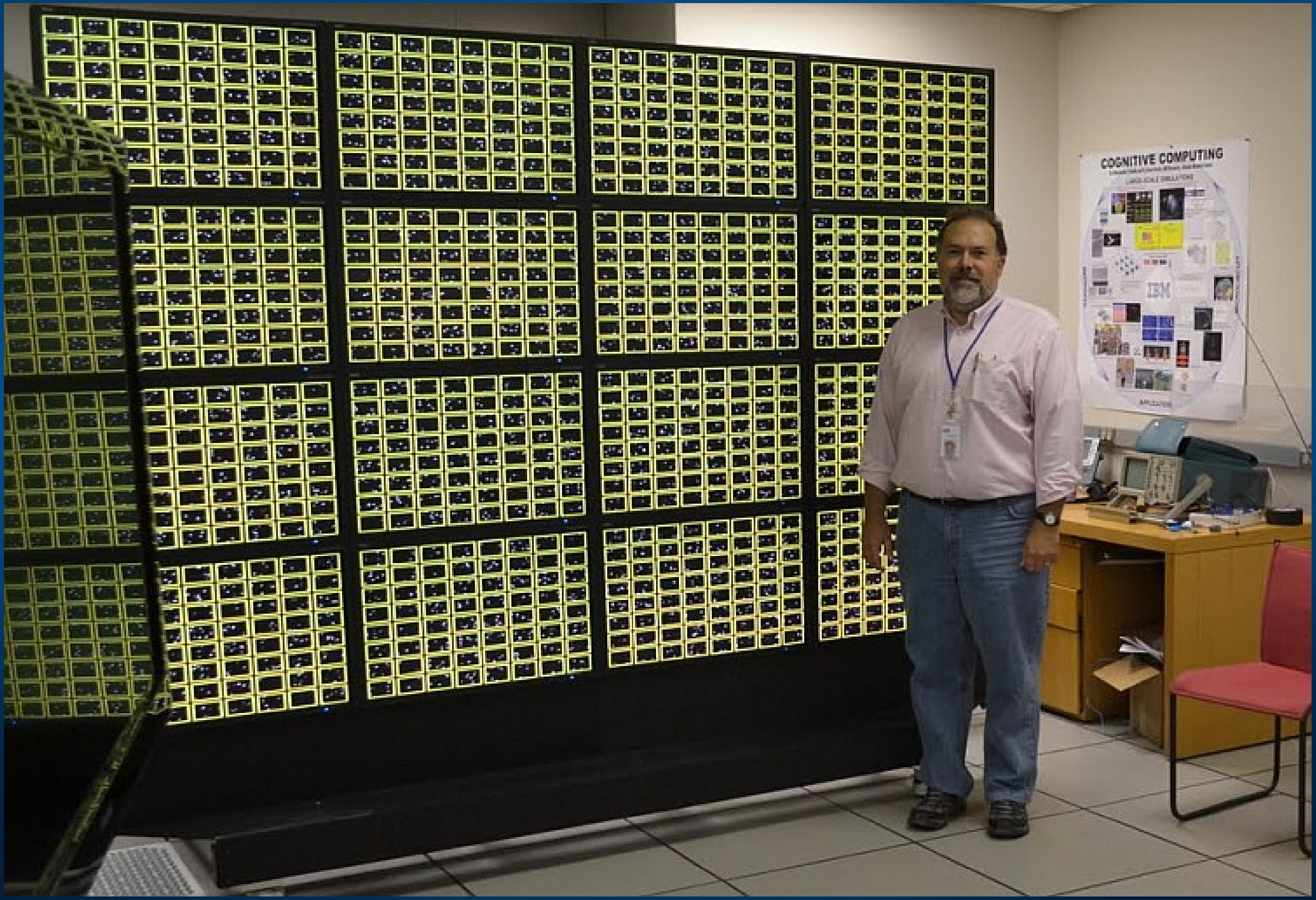
Many neuromorphic chips,
including Intel Loihi.

Jülich Forschungszentrum
36 M€ for neuromorphic
and quantum computing.



Neuromorphic wall

1024 TN chips, or 1 B neurons and 256 B synapses.
Complexity of horse brain, 1/4 gorilla, 1/6 chimpanse.



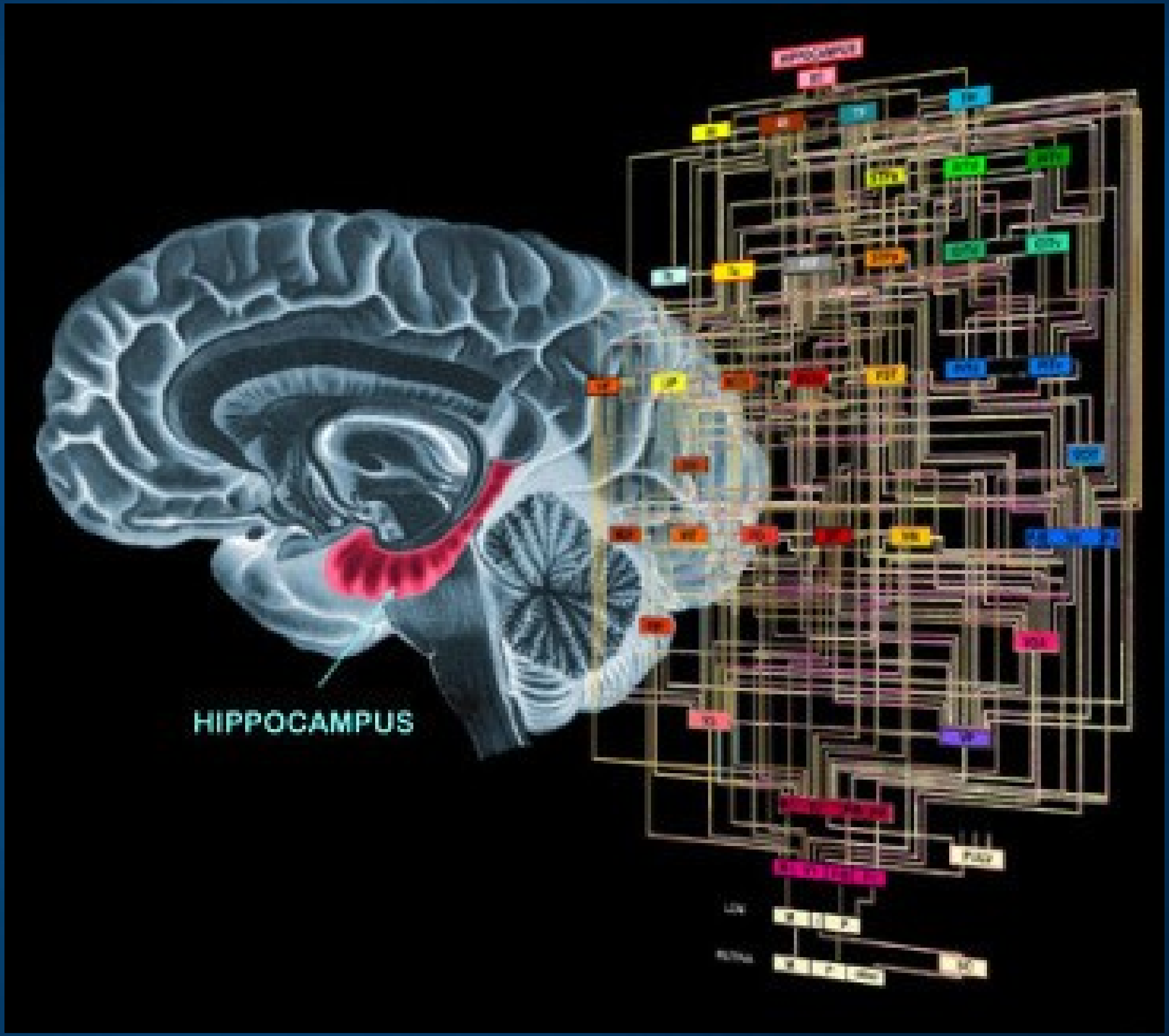
BICA, Brain-Inspired Cognitive Architecture

Understanding the brain from engineering perspective means to build a model of the brain showing similar functions.

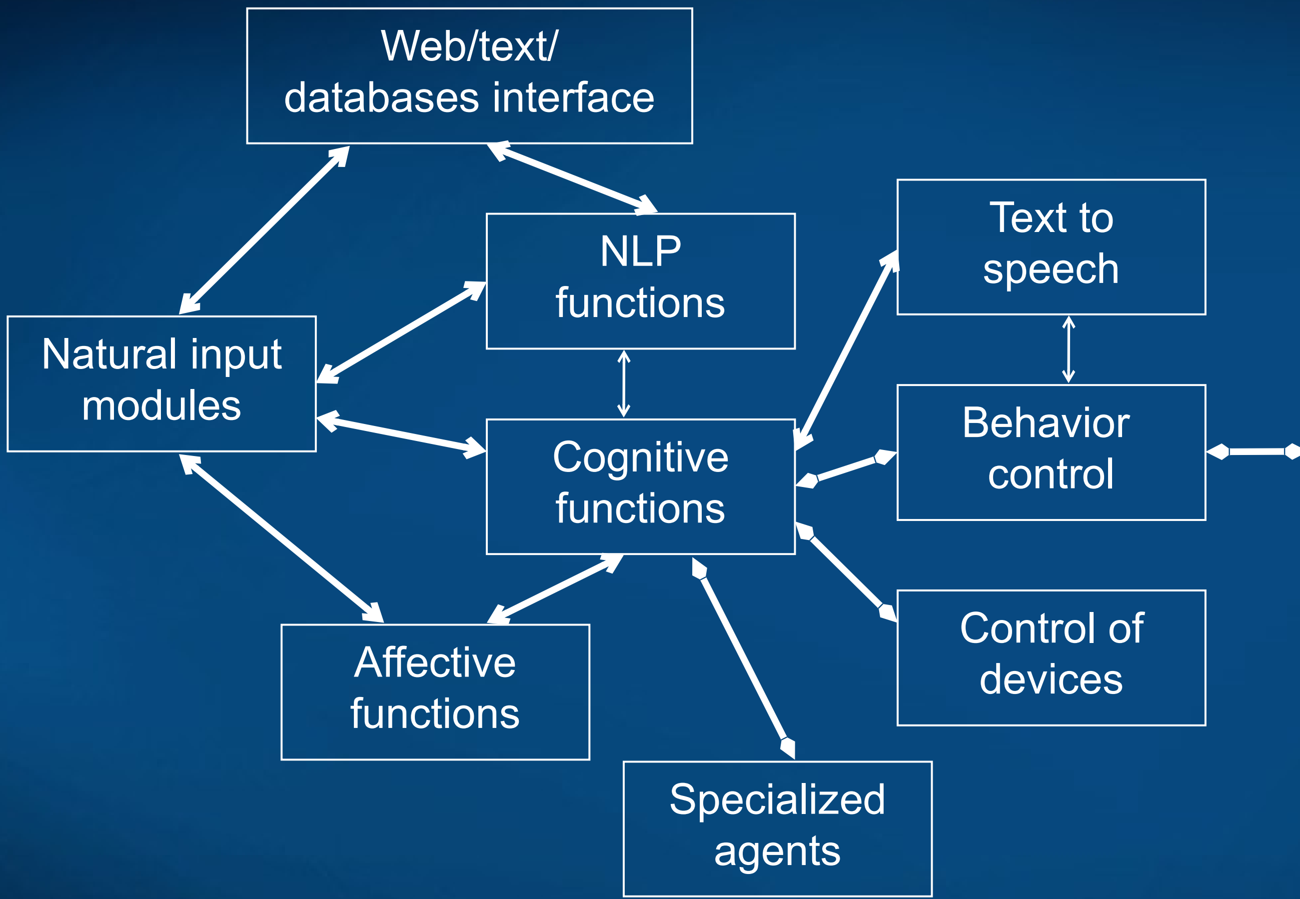
Cognitive informatics, Neurocognitive Informatics.

BICA = Brain Inspired Cognitive Architecture.

Review: Duch, Oentaryo, Pasquier, Cognitive architectures: where do we go from here? 2008

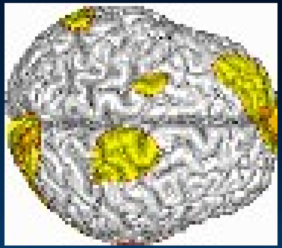


DREAM top-level architecture



DREAM project (2003), focused on perception (visual, auditory, text inputs), cognitive functions (reasoning based on perceptions), natural language communication in well defined contexts, real time control of the simulated/physical head. Now Amazon, Google, Apple do it … Now in watches …

Neuroscience => AI



Examples of recent AI systems inspired by neuroscience:
(A) **Intuitive physics knowledge**, reason and make predictions about the physical interaction between objects, predict trajectories, collisions, gravitational forces.

(B) **Scene understanding** through structured generative models. Recurrent network attends to one object at a time, infers its attributes, and performs the appropriate number of inference steps for each input image in realistic scene.

(C) **Unsupervised learning of core object properties** by deep generative model based on variational auto-encoder, that can learn intuitive concepts such as ‘‘objectness,’’ being able to support zero-shot transfer (i.e., reasoning about position or scale of an unseen object with a novel shape).
(D) **One-shot generalization** in deep sequential generative models that specify a causal process for generating the observed data using a hierarchy of latent variables, with attentional mechanisms supporting sequential inference, mirroring human abilities to generalize from a single concept.
(E) **Imagination of realistic 3D environments** in deep neural networks by an action-conditional recurrent network model, reinforcement learning in simulation-based planning.

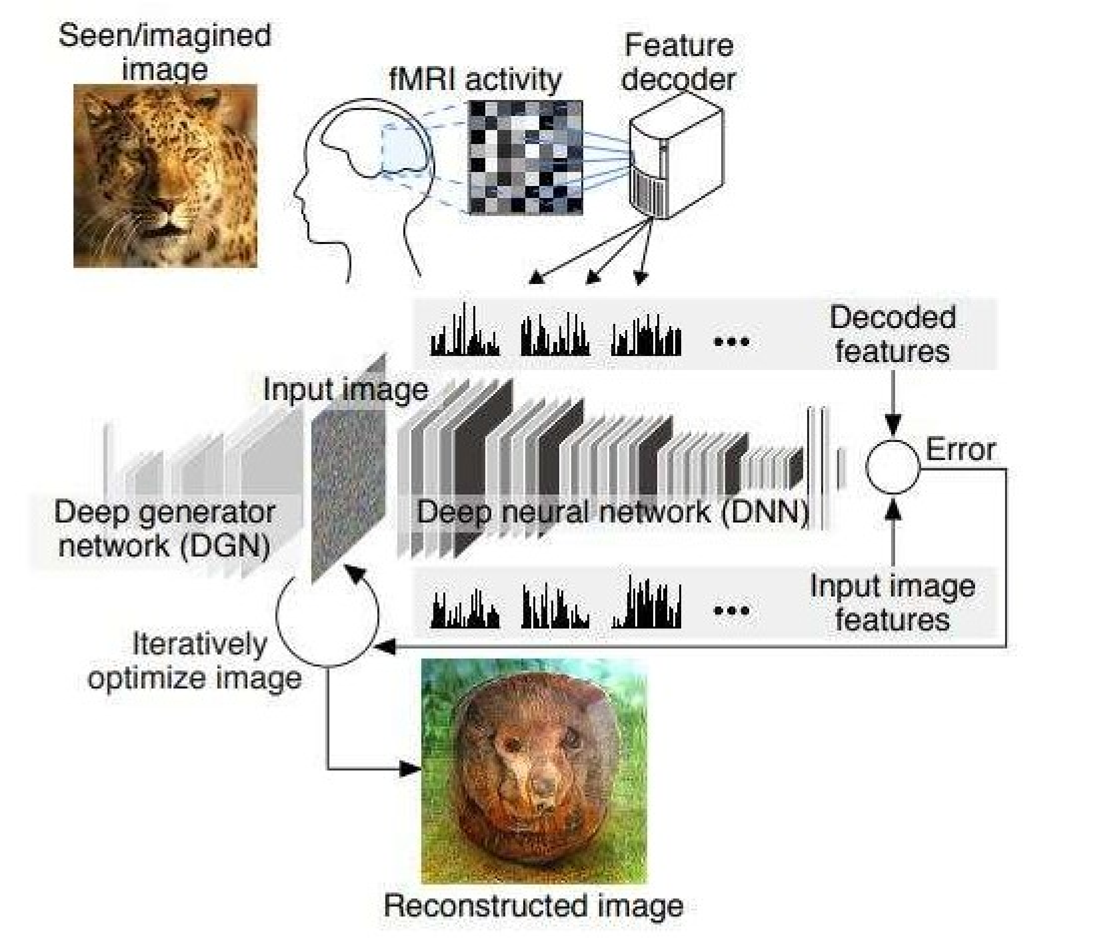
fMRI ⇔ CNN

Convert activity of the brain into the mental images that we are conscious of.

Try to estimate features at different brain areas/cortical layers.

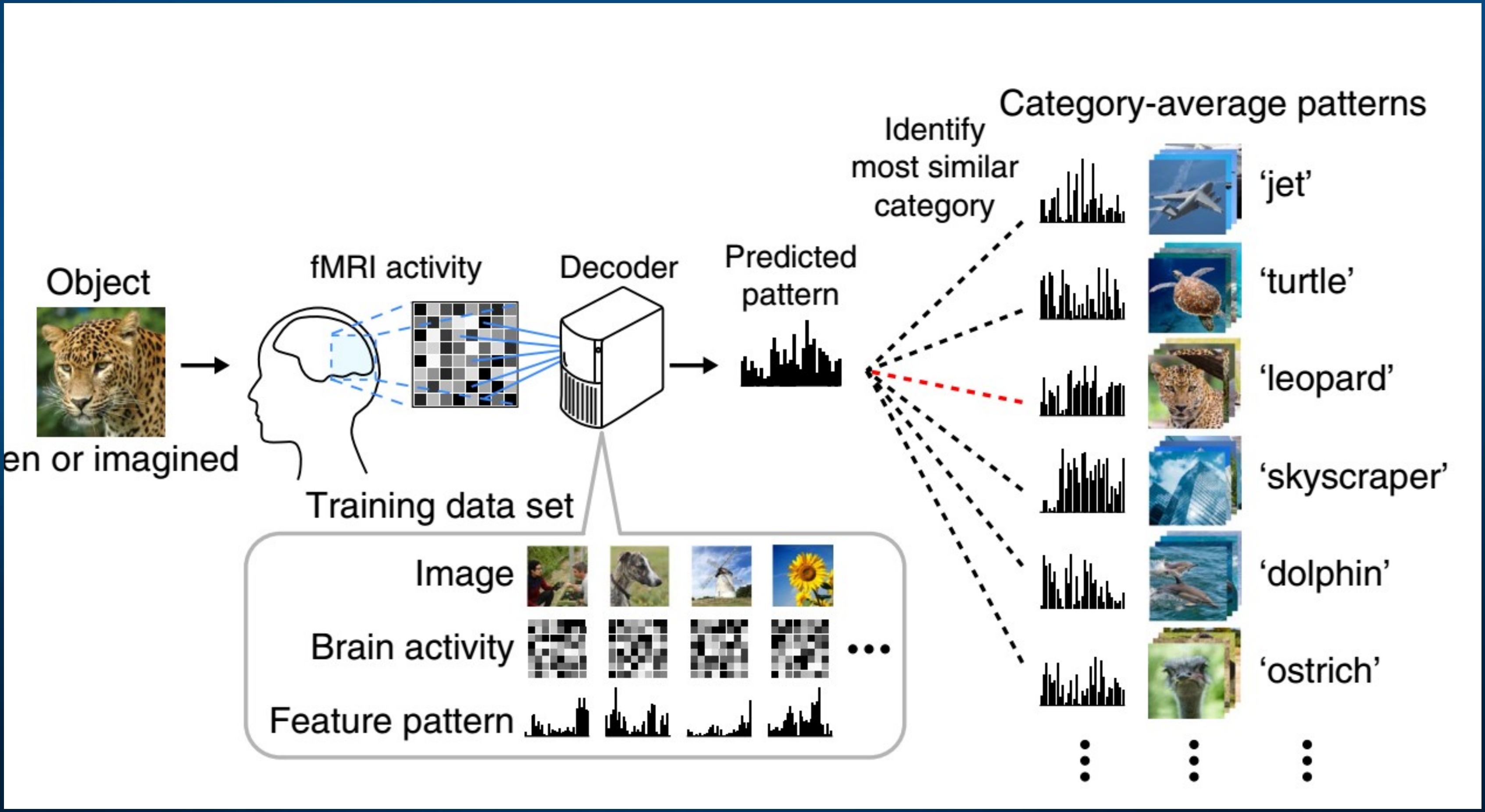
8-layer convolution network, ~60 mln parameters, feature vectors from randomly selected 1000 units in each layer are used to represent images at different level of processing.

Output: vector of features that may be used to reconstruct image.



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 categorization (~20 categories).

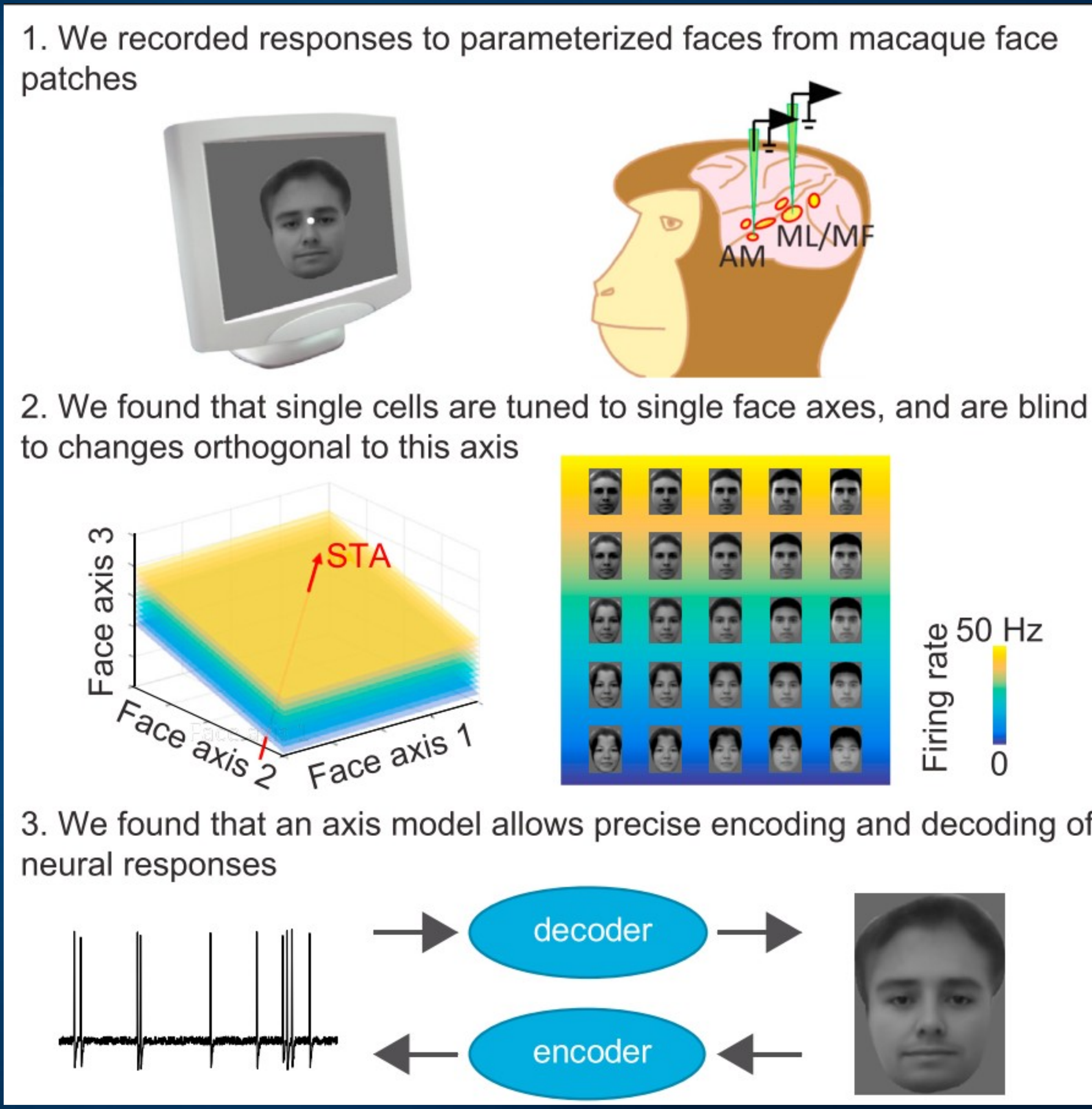
Dreams, thoughts … can one hide what has been seen and experienced?

Neural screen

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

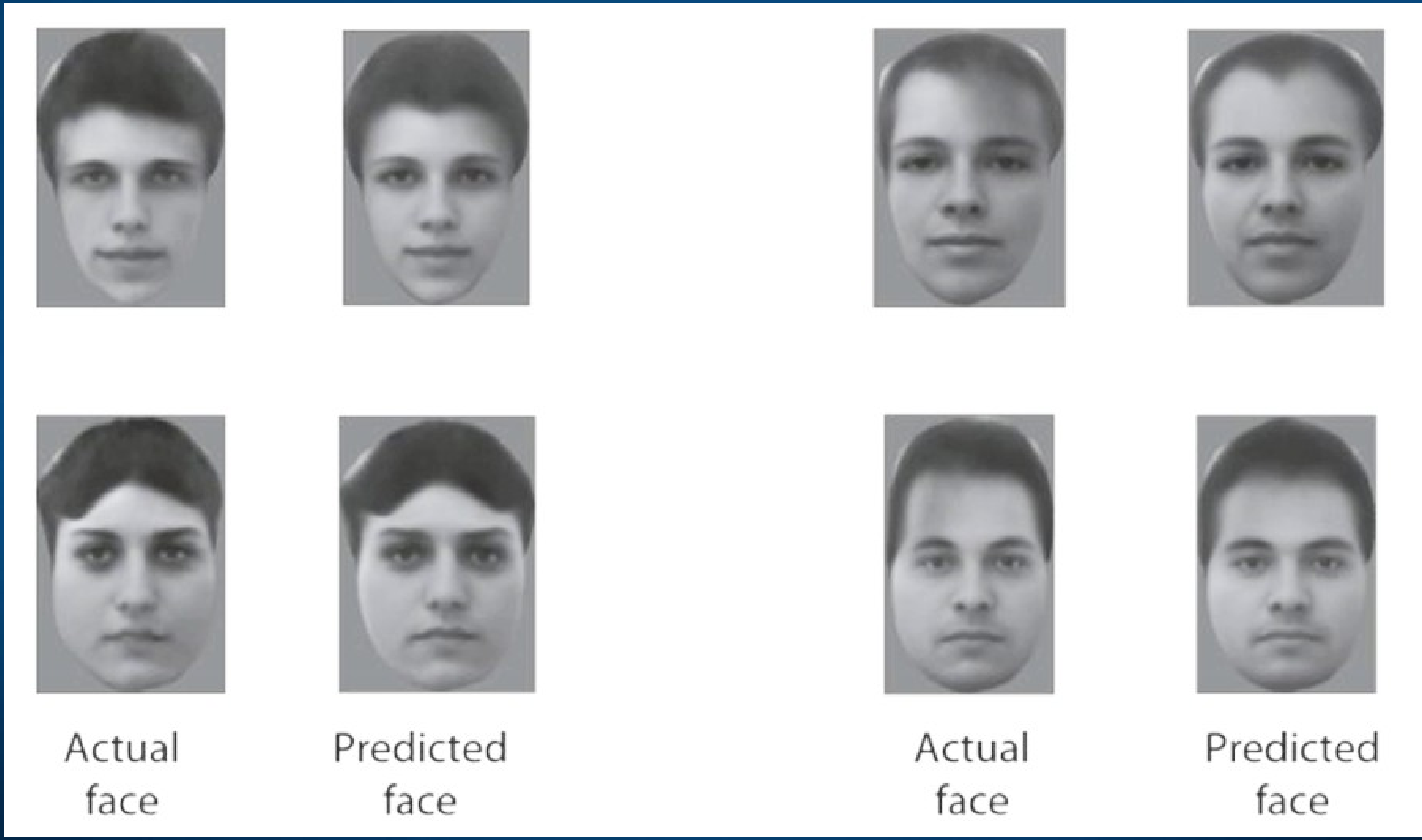
L. Chang and D.Y. Tsao, “**The code for facial identity in the primate brain**” *Cell* 2017

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



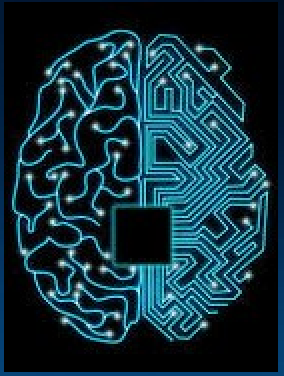
Mental images

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

AI=>Neuroscience



ML techniques are basic tools for analysis of neuroimaging data.

Ideas from animal psychology helped to give birth to reinforcement learning (RL) research. Now **key concepts from RL inform neuroscience**.

Activity of midbrain dopaminergic neurons in conditioning paradigms has a striking resemblance to temporal difference (TD) generated prediction errors - **brain implements a form of TD learning!**

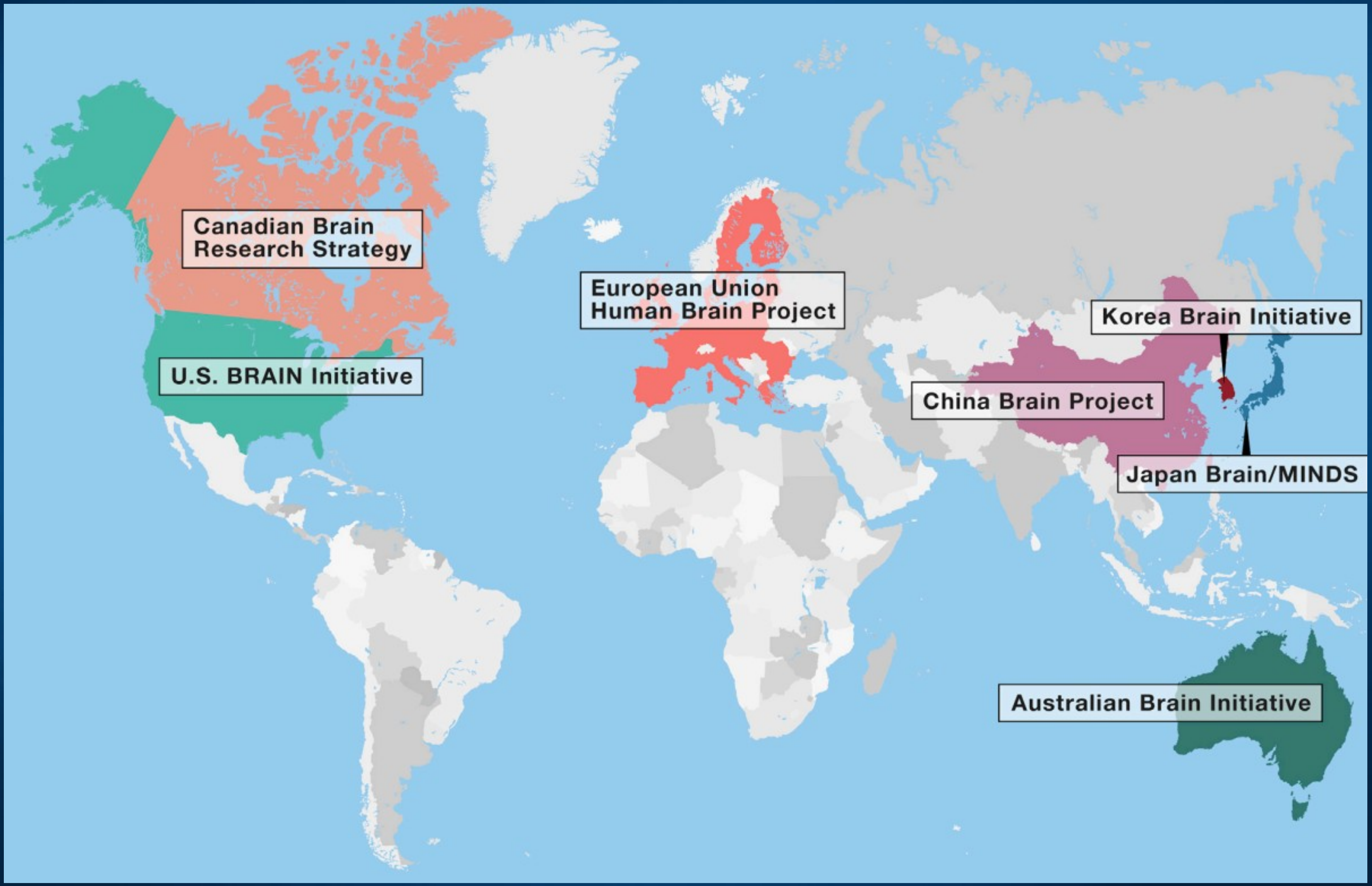
CNN ⇔ interpret neural representations in high-level ventral visual stream of humans and monkeys, finding evidence for deep supervised networks.

LSTM architecture provides key insights for development of working memory, gating-based maintenance of task-relevant information in the prefrontal cortex.

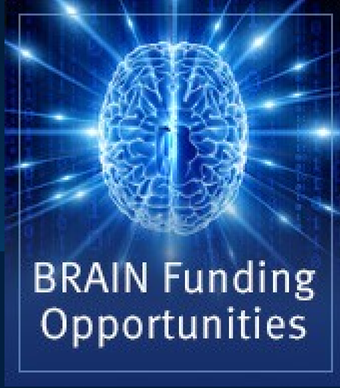
Backpropagation with symmetric feedback and feedforward connectivity is not realistic, but random backward connections allow the backpropagation algorithm to function effectively through a process whereby adjustment of the forward weights allows backward projections to transmit useful teaching signals.

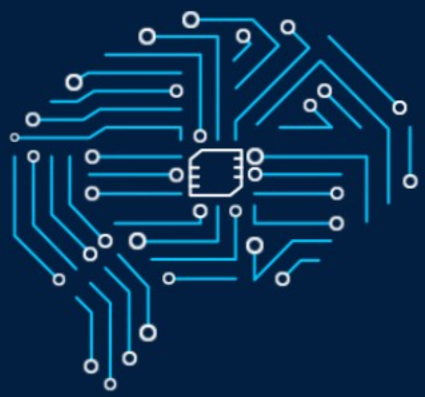
Global Brain Initiatives

International Brain Initiatives



BRAIN
INITIATIVE





Advance Neurotechnologies

Accelerate the development and application of new neurotechnologies.

Support multi-disciplinary teams and stimulate research to rapidly enhance current neuroscience technologies and catalyze innovative scientific breakthroughs.

Human Brain Project, EU Flagship, and Obama BRAIN Initiative (2013):
Brain **R**esearch through **A**dvancing **I**nnovative **N**eurotechnologies.

"Develop new technologies to explore how the brain's cells and circuits interact at the speed of thought, ultimately uncovering the complex links between brain function and behavior. Explore how the brain records, processes, uses, stores, and retrieves vast quantities of information. Help bring safe and effective products to patients and consumers."

Since 2013 numerous exciting developments in neurotechnology and our understanding of the brain have been made by scientists across the globe.

The mission of IEEE Brain is to facilitate cross-disciplinary collaboration and coordination to advance research, standardization and development of technologies in neuroscience to help improve the human condition.

20 IEEE Societies are involved, including:

IEEE Computational Intelligence Society; Computer Society; Consumer Electronics Society; Digital Senses Initiative; Robotics and Automation Society; Sensors Council; Signal Processing Society; Society on Social Implications of Technology; **Systems, Man, and Cybernetics Society**, International Neuroethics Society, and a few other societies.

Most these societies are also involved in artificial intelligence.

Satya Nadella (CEO, Microsoft): to celebrate National Disability Employment Awareness Month, I'm sharing examples of how technology can be applied to empower the more than one billion people with disabilities around the world.

Workshop on Brain-Machine Interface Systems
Global Current and Emerging Brain Initiative Meeting
Brain Hackathon

IEEE SMC
Systems, Man, and Cybernetics Society

Part of the Brain-Machines Interface Workshop and SMC2018.

The IEEE SMC Society and the IEEE President, James Jefferies, are proud to invite you on to a special meeting of **Global Current and Emerging Brain Initiative leaders** and representatives from other groups working on large-scale multi-year brain projects from Australia, Canada, China, Europe (HBP), Japan, Korea, New Zealand, **Poland**, Russia, and US (NSF and NIH), with representatives from the **IEEE Brain Initiative**, International Neuroethics Society, industry, and other stakeholders.

IEEE welcomes collaborative discussions with all stakeholders to better align and integrate IEEE with other existing brain efforts.

incf | Neuro Informatics 2019

International Neuroinformatics Coordination Facility (INCF) goal: integrate and analyze diverse data across scales, techniques, and species to understand the brain and positively impact the health and well being of society.

Polish INCF Node, established in Warsaw at Nencki Institute, since 2017 at the Nicolaus Copernicus University in Toruń.

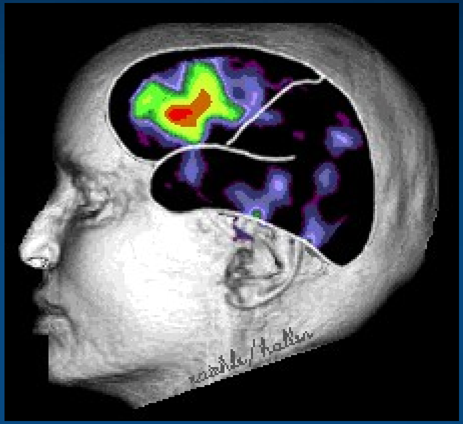
12th INCF Congress on Neuroinformatics and INCF Assembly, Warsaw 9/2019. Neuroimaging, computational neuroscience, artificial intelligence.

Polish Ministry of Science and Higher Education has signed Memorandum of Understanding opening the way to full INCF membership.

Polish Brain Council (Polska Rada Mózgu) started in 2013, working on “Brain Plan for Poland – Strategy for People with Brain Diseases”.

Brain networks:
space for neurodynamics

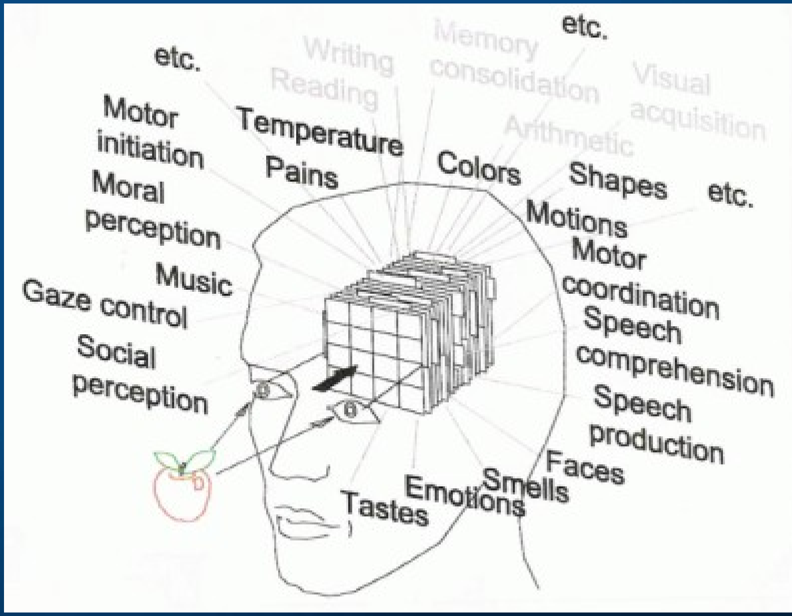
Brains ⇔ Minds



Define mapping S(M)⇔S(B), as in BCI.
How do we describe the state of mind?

Verbal description is not sufficient unless words are represented in a space with dimensions that measure different aspects of experience.

Stream of mental states, movement of thoughts ⇔ trajectories in psychological spaces.

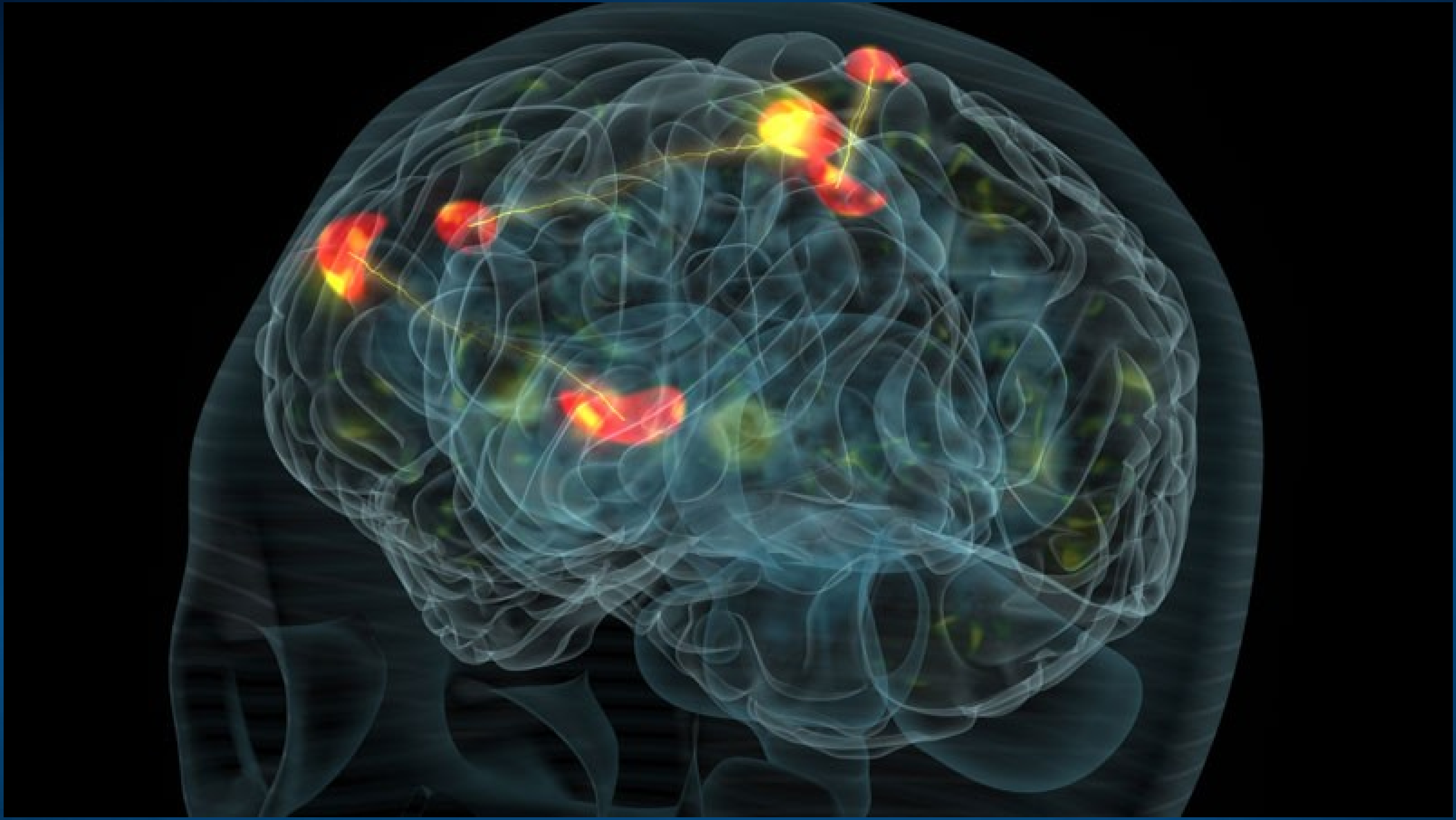


Two problems: discretization of continuous processes for symbolic models,
and lack of good phenomenology – we are not able to describe our mental states.

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

W. Duch, Mind space (1994);
E. Schwitzgabel, Perplexities of Consciousness. MIT Press 2011.

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.

On the threshold of a dream …

Final goal: optimize brain processes!

Although whole brain is always active we are far from achieving full human potential. To repair damaged brains and increase efficiency of healthy brains we need to understand brain processes:

1. Find fingerprints of specific activity of brain structures (regions, networks) using neuroimaging technology (and new neurotechnologies).
2. Create models of cognitive architectures that help to understand information processing in the brain.
3. Create new diagnostic and therapeutic procedures.
4. Use neurofeedback based on decoding and changes in connectivity and close-loop system that directly stimulate the brain.

G-tec wireless NIRS/EEG on my head.

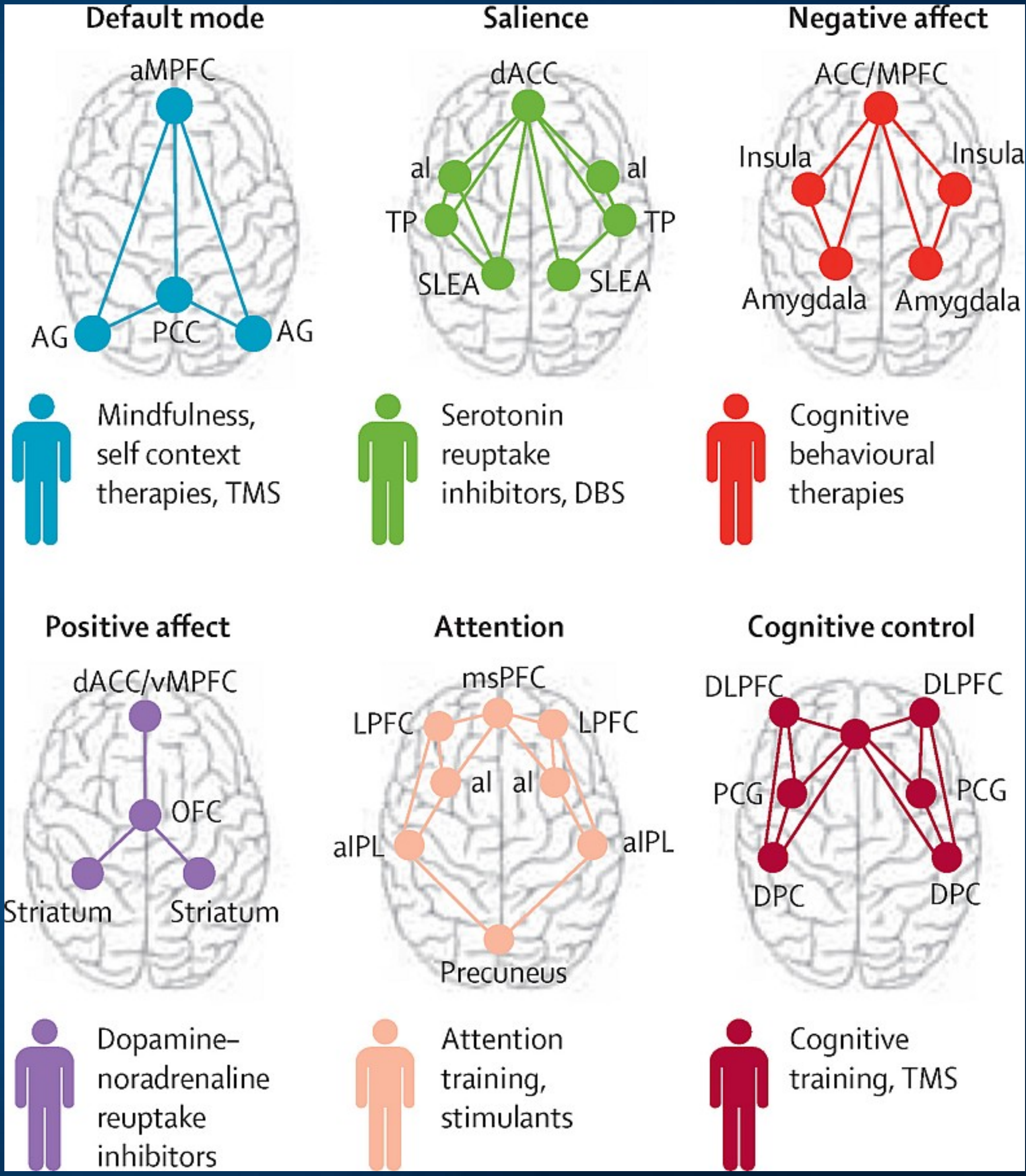
Duch W, *Brains and Education: Towards Neurocognitive Phenomics*. 2013

Multi-level phenomics

Instead of classification of mental disease by symptoms use **Research Domain Criteria** (RDoC) matrix based on **multi-level neuropsychiatric phenomics** describing large brain systems deregulation.

1. **Negative Valence Systems,**
2. **Positive Valence Systems**
3. **Cognitive Systems**
4. **Social Processes Systems**
5. **Arousal/Regulatory Systems**

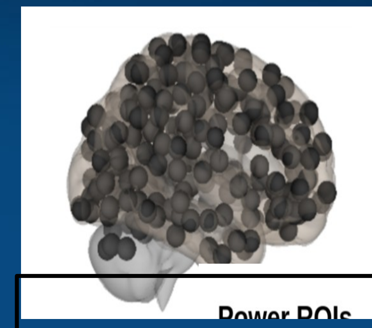
Include genes, molecules, cells, **circuits**, physiology, behavior, self-reports and paradigms.



CMIT: scanner GE Discovery MR750 3T

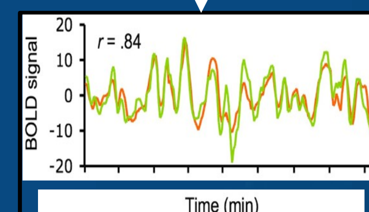
Human connectome and MRI/fMRI

Node definition (parcelation)

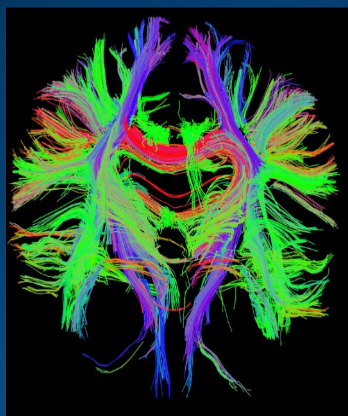


Signal extraction

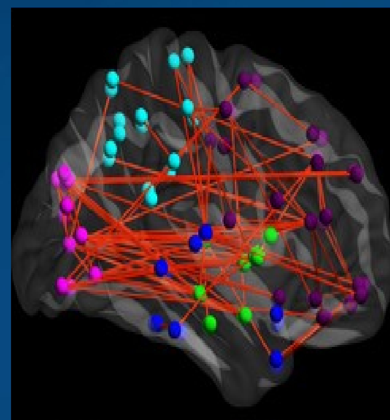
Correlation calculation



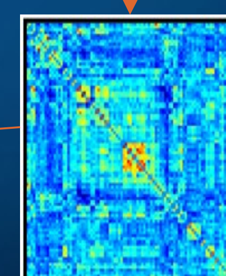
Structural connectivity



Functional connectivity

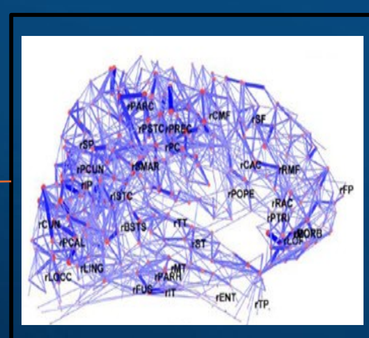


Correlation matrix

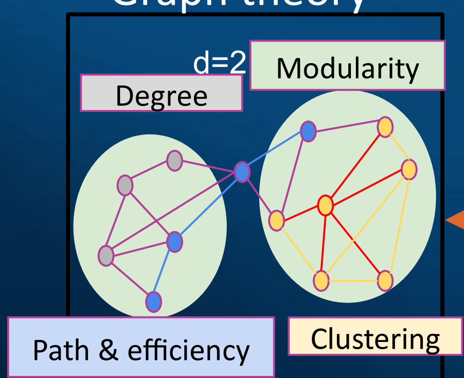


Binary matrix

Whole-brain graph



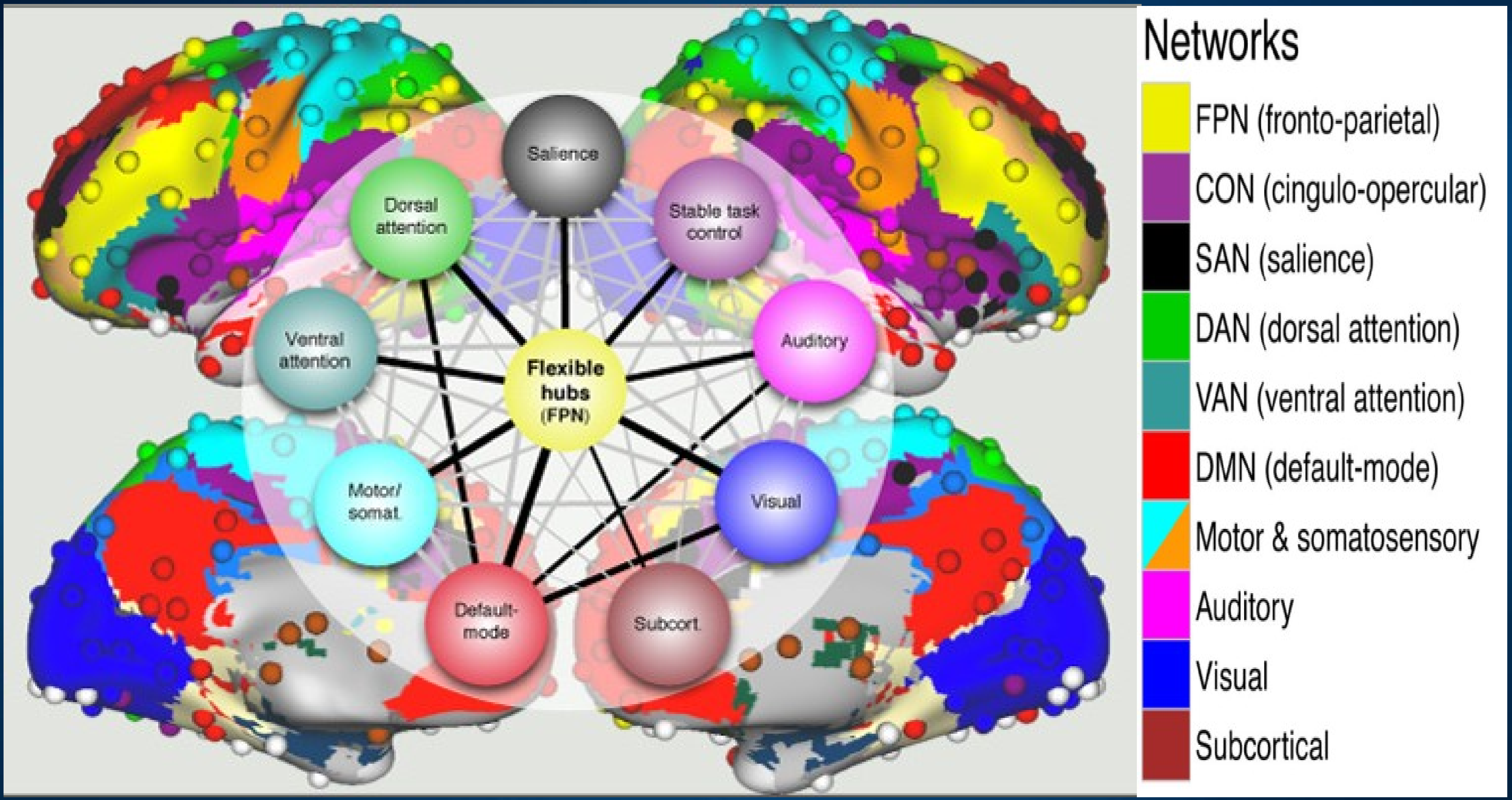
Graph theory



Many toolboxes available for such analysis.

Bullmore & Sporns (2009)

Neurocognitive Basis of Cognitive Control



Central role of fronto-parietal (FPN) flexible hubs in cognitive control and adaptive implementation of task demands (black lines=correlations significantly above network average). Cole et al. (2013).

Brain Fingerprints

fMRI: fingerprints of brain cognitive activity = **V(X,t)** voxel intensity of fMRI BOLD signal changes, contrasted between task or reference/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.

In search of the sources of brain's cognitive activity

Project „Symfonia”, 2016-21

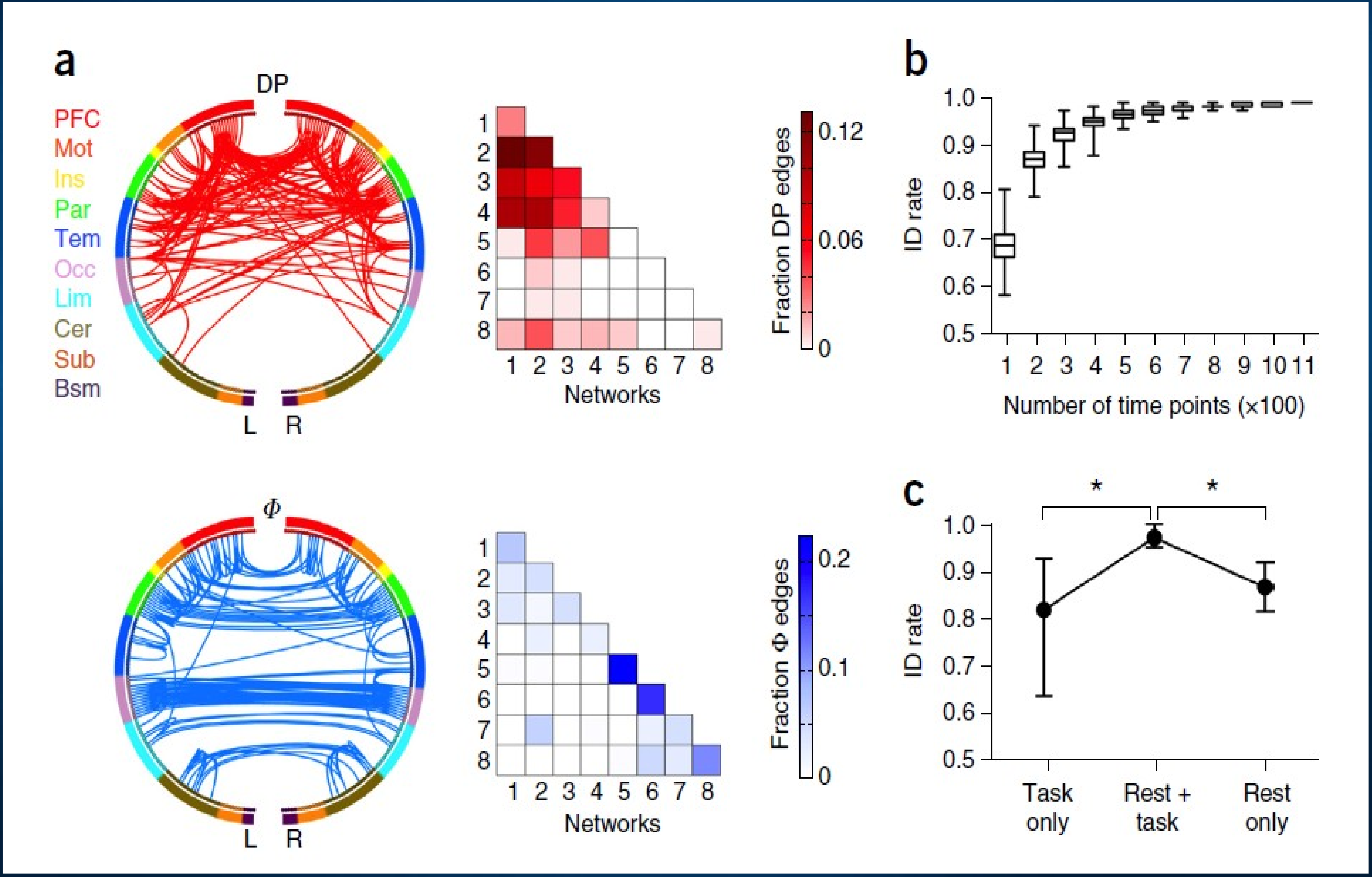
FACULTY OF PHYSICS, ASTRONOMY AND INFORMATICS

CENTRE FOR MODERN INTERDISCIPLINARY TECHNOLOGIES

INSTITUTE OF PHYSIOLOGY AND PATHOLOGY OF HEARING

nencki institute of experimental biology

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

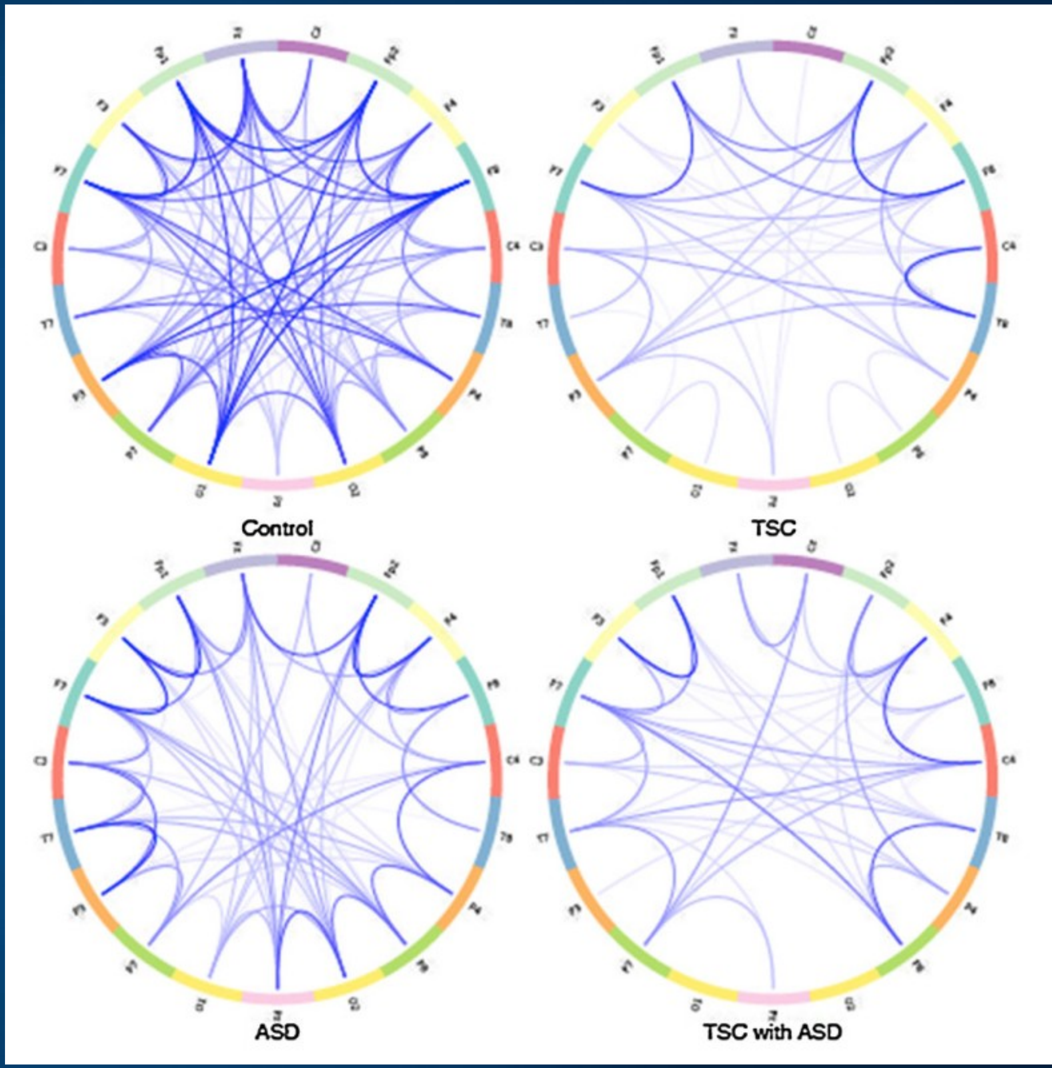


ASD: pathological connections

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

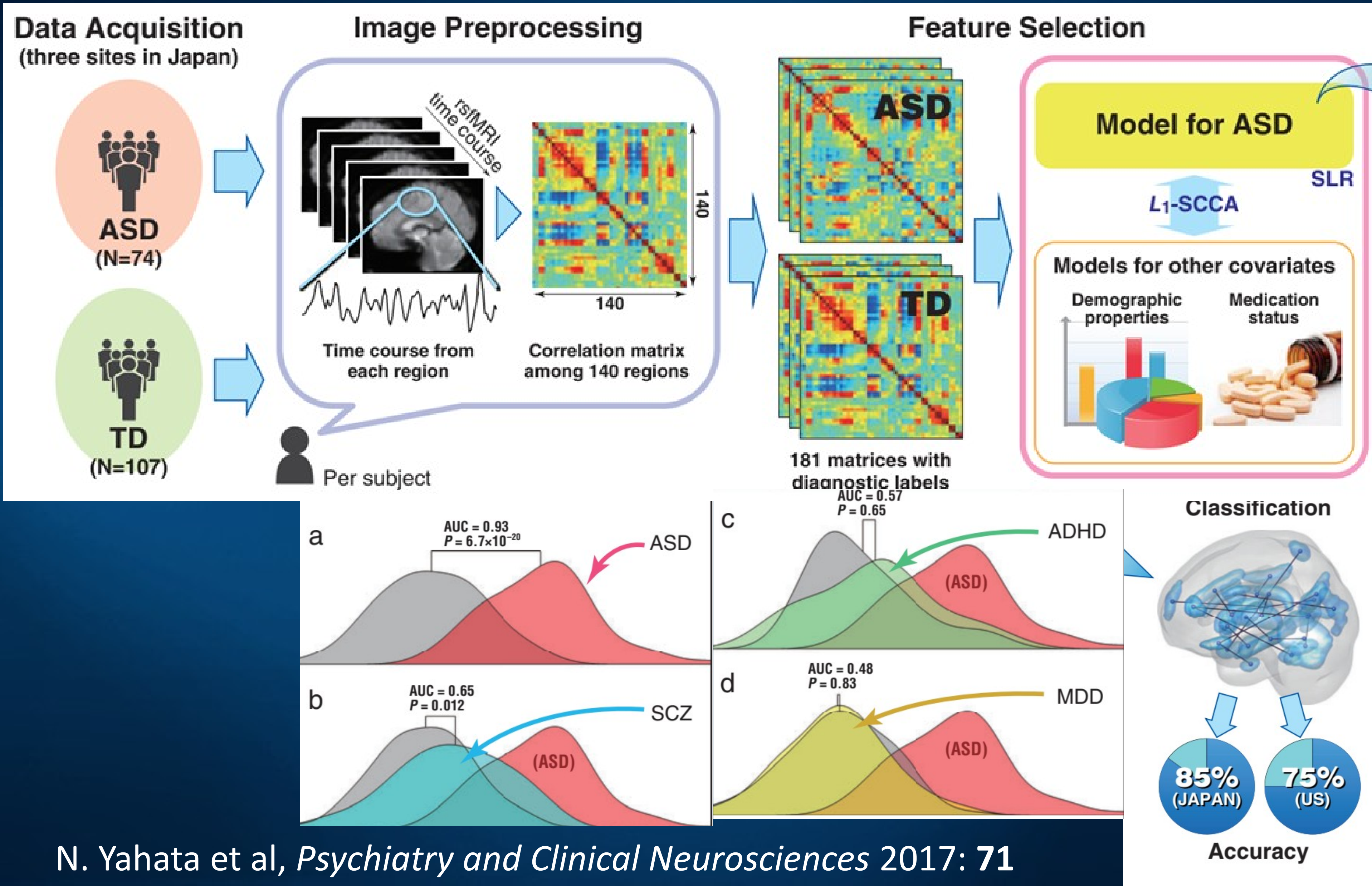
Coherence between electrodes. Weak or missing connections between distant regions prevent ASD/TSC patients from solving more demanding cognitive tasks.

Network analysis becomes very useful for diagnosis of changes due to the disease and learning; **correct your networks**!



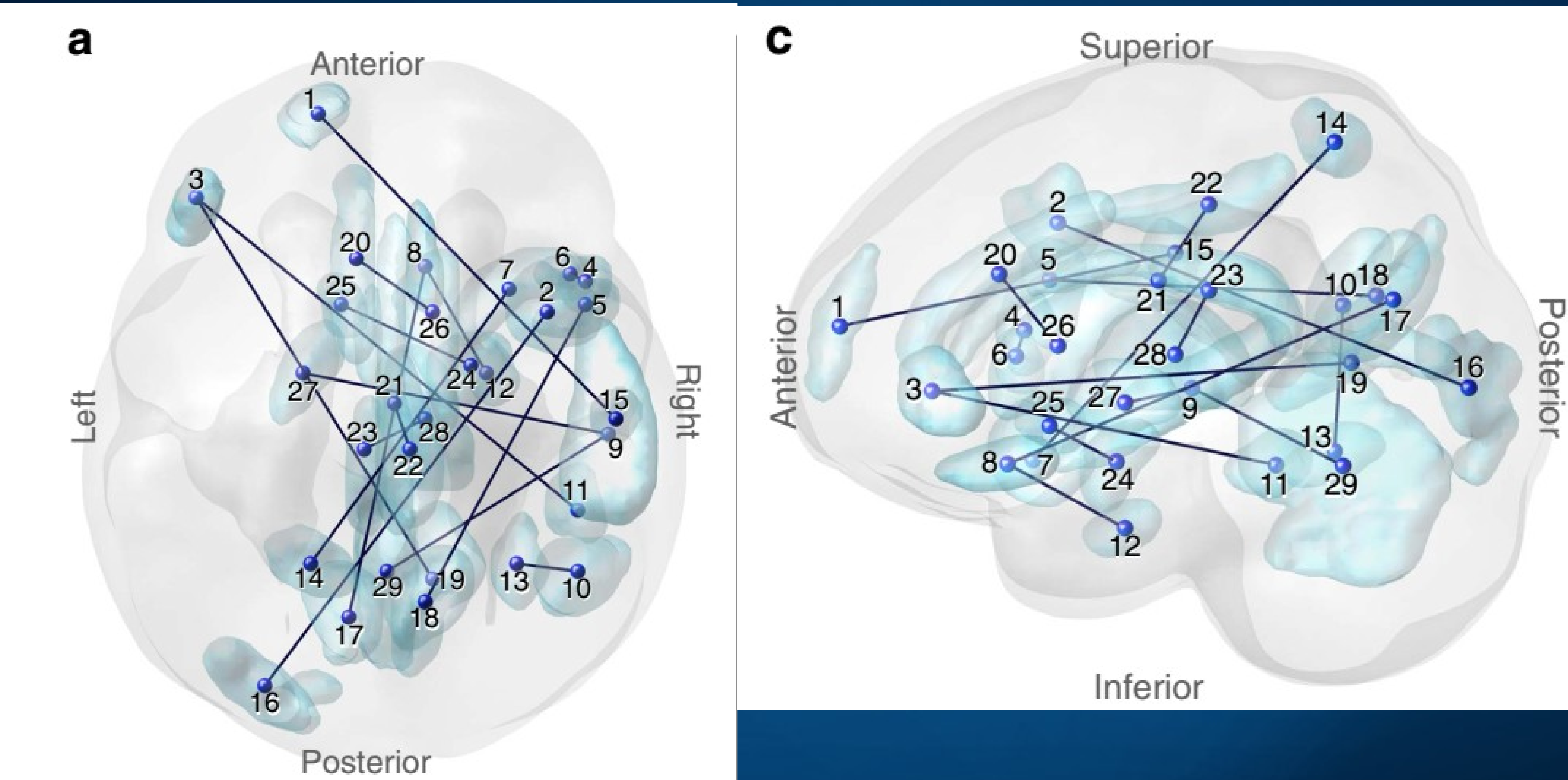
J.F. Glazebrook, R. Wallace, Pathologies in functional connectivity, feedback control and robustness. Cogn Process (2015) 16:1–16

Diagnosis based on fMRI



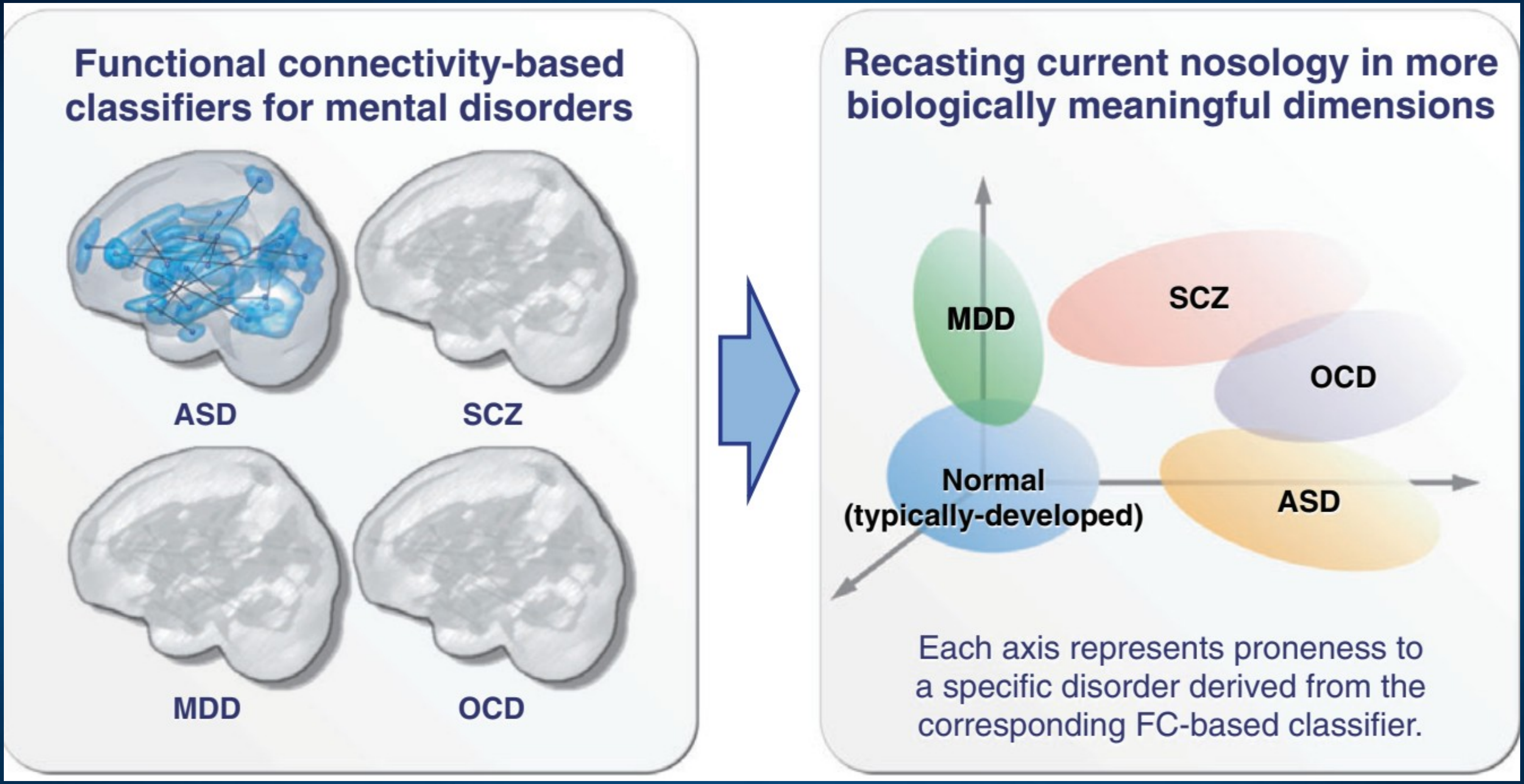
N. Yahata et al, *Psychiatry and Clinical Neurosciences* 2017: **71**

Selected connections



N. Yahata et al (2016): 29 selected regions (ROI) and 16 connections are 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.

Propensity to 4 disorders



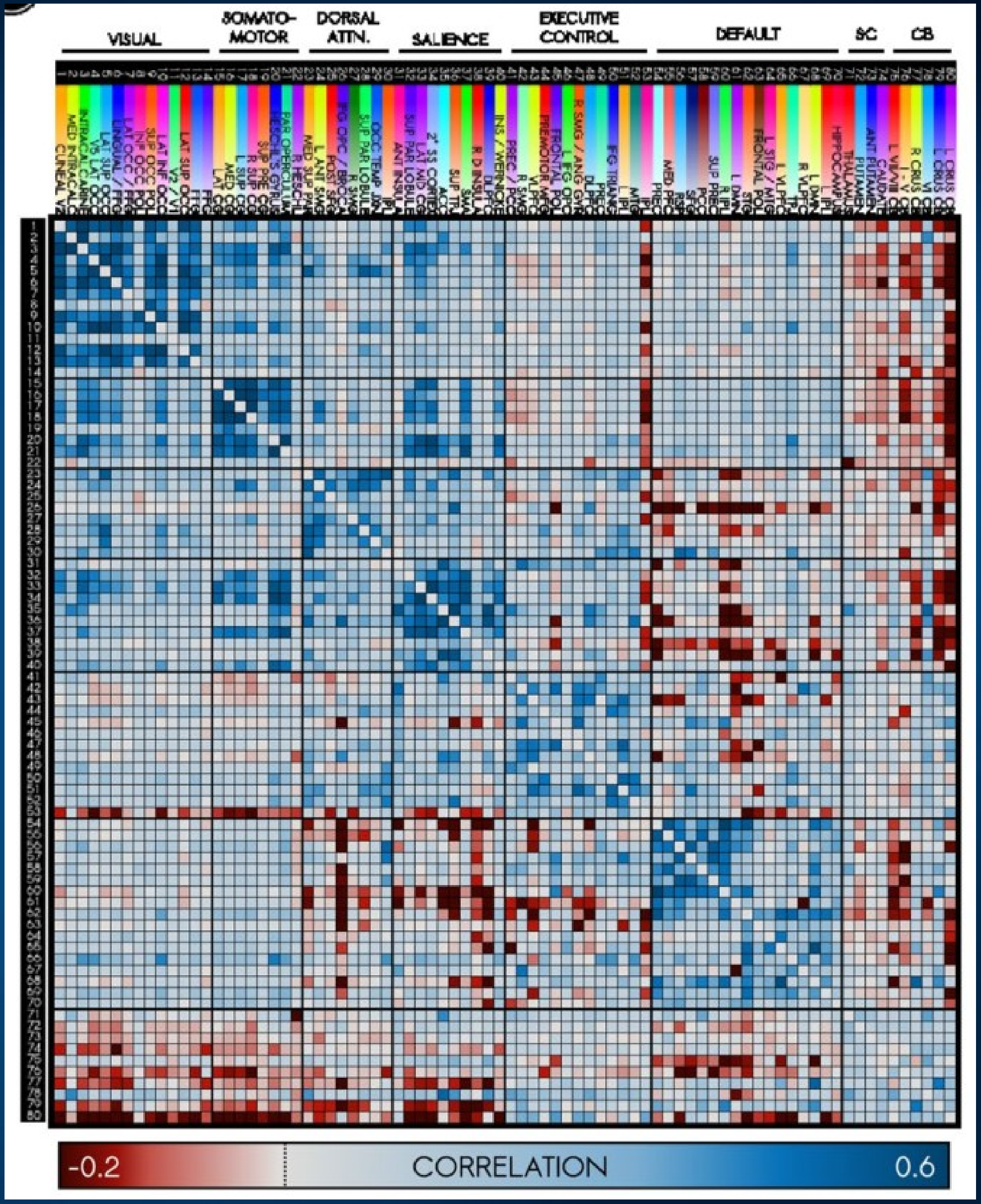
MDD, major depressive disorder, SCZ, schizophrenia, OCD, obsessive compulsive disorder, in ASD and SCZ axis. Experimental biomarkers based on fMRI data.
N. Yahata et al, *Psychiatry and Clinical Neurosciences* 2017; **71**: 215–237

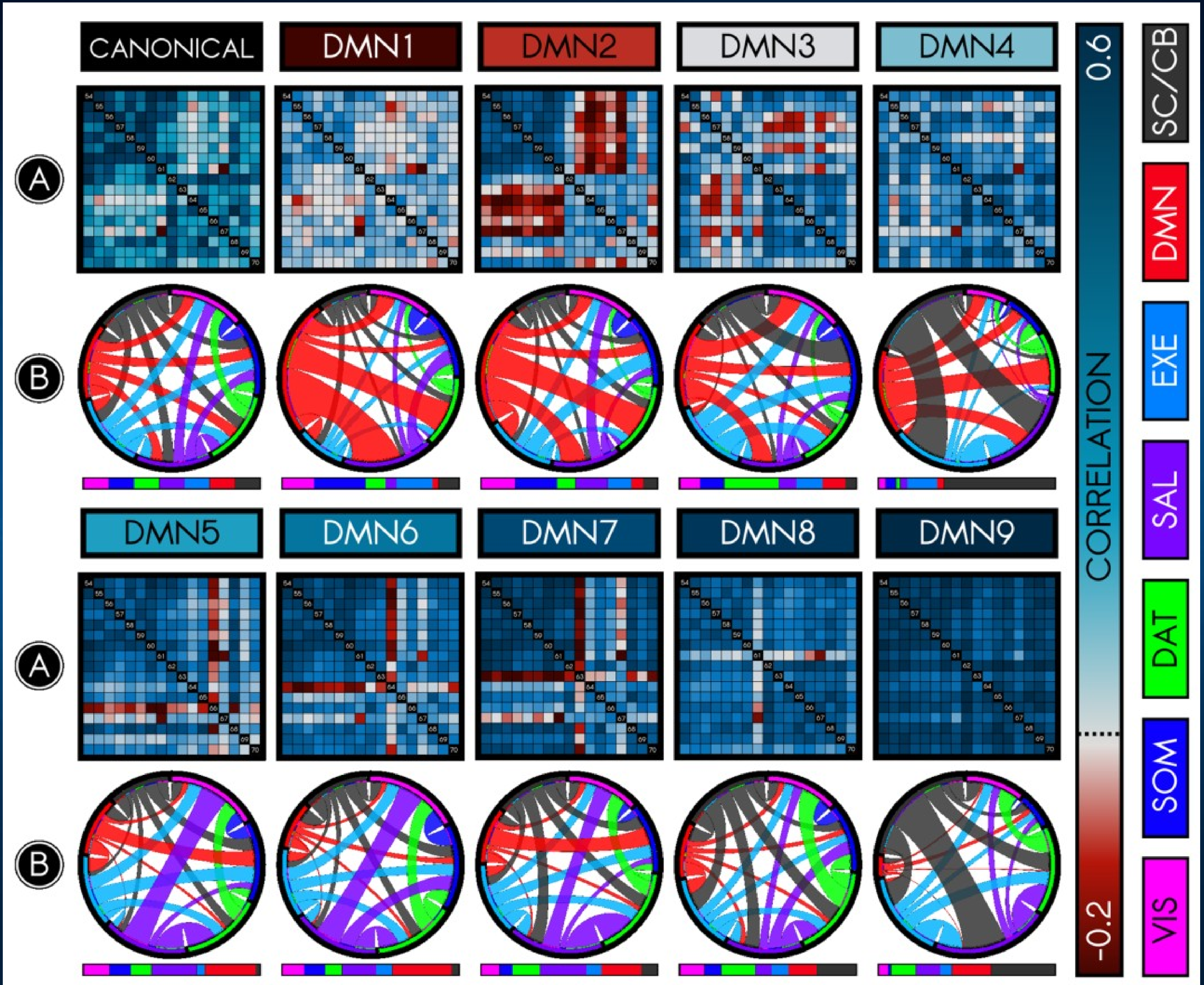
Ciric et.al. (2017). Contextual connectivity: A framework for understanding the intrinsic dynamic architecture of large-scale functional brain networks. *Scientific Reports*.

Correlations of 6 canonical networks + subcortical (SC) nad cerebellum (CB).

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.




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

Dynamic functional brain networks

Brain modules and cognitive processes

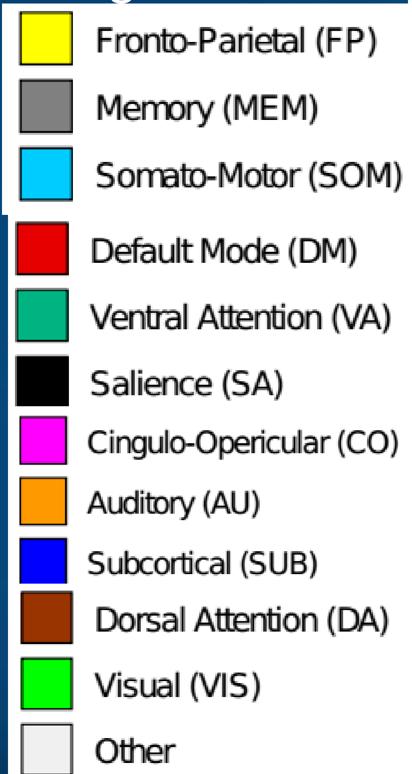
Simple and more difficult tasks, requiring the whole-brain network reorganization.

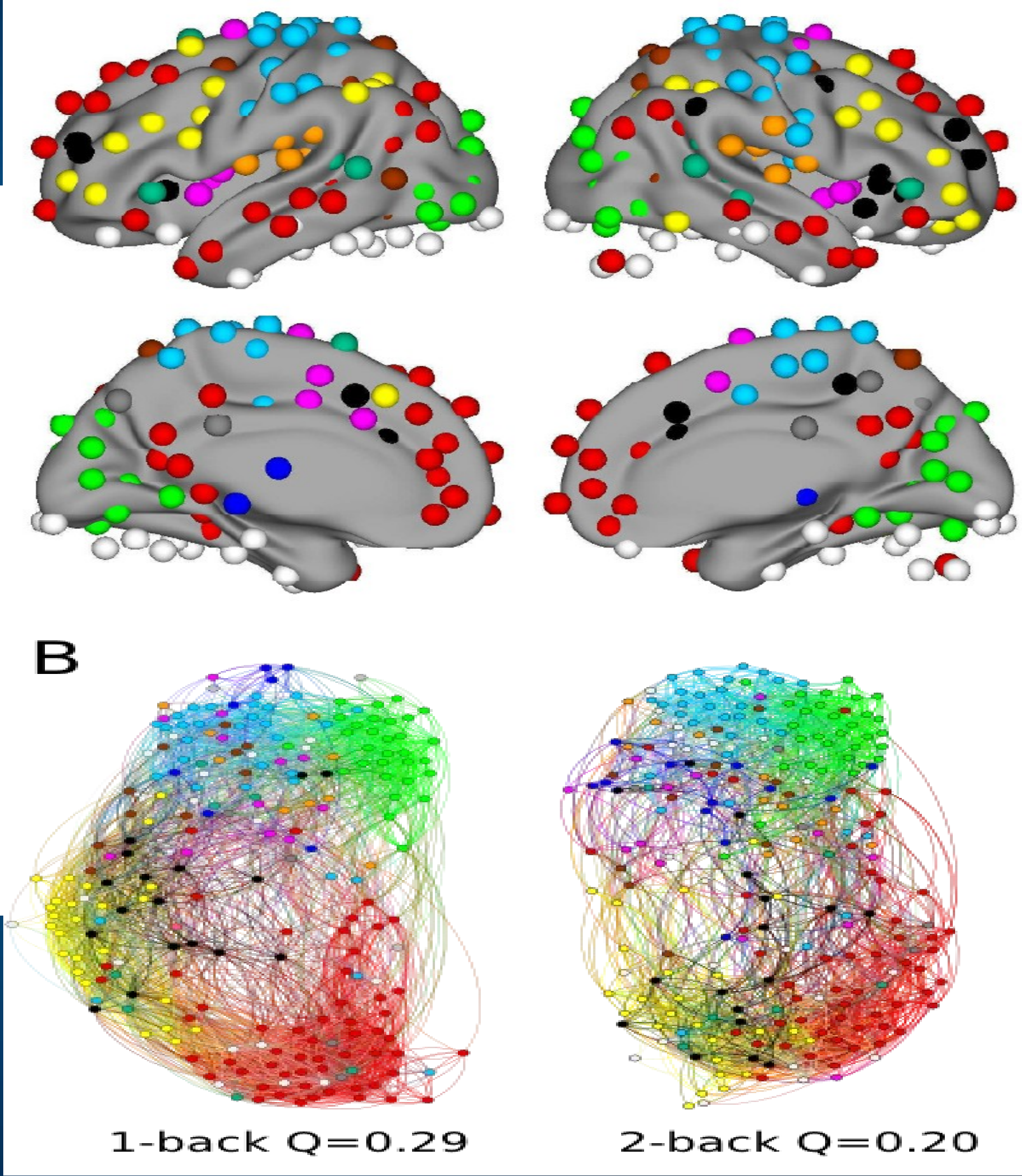
Left: 1-back

Right: 2-back

Average over 35 participants.

Left and midline sections.





K. Finc et al, HBM (2017).

Brain modules and cognitive processes

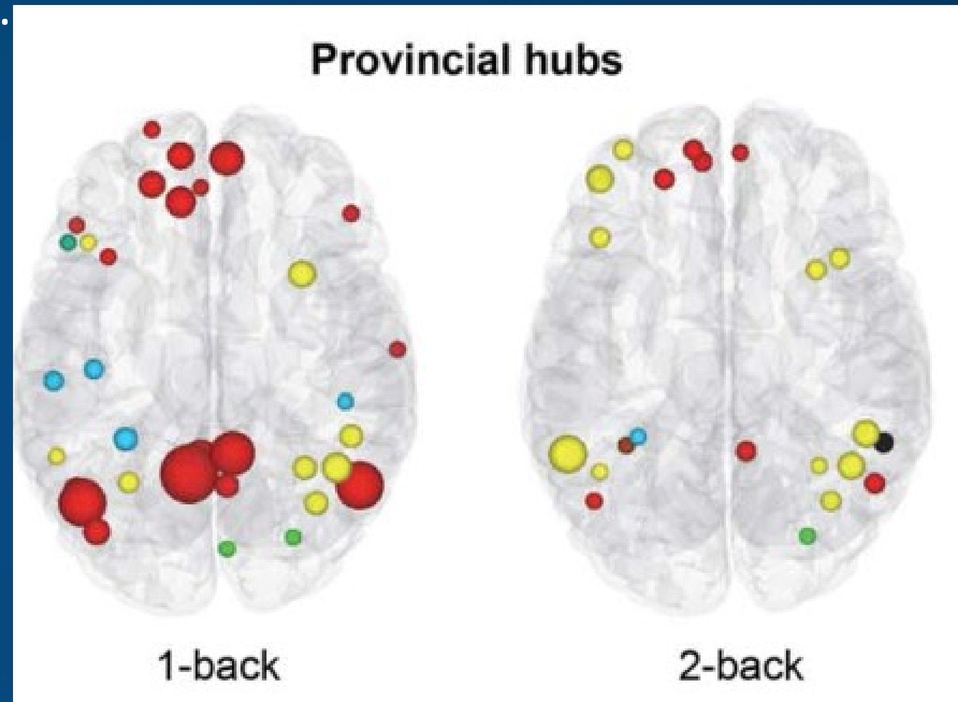
Simple and more difficult tasks, requiring the whole-brain network reorganization.

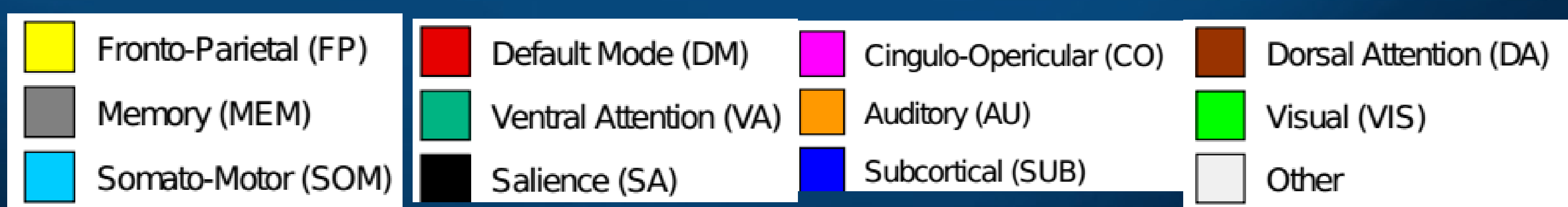
Left: 1-back local hubs

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.

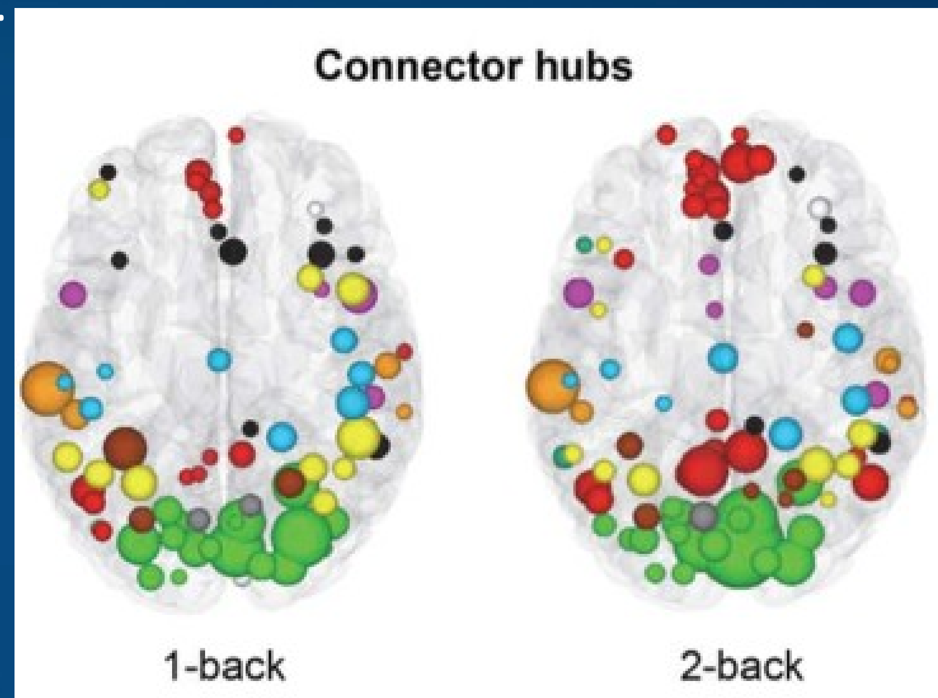
Left: 1-back connector hubs

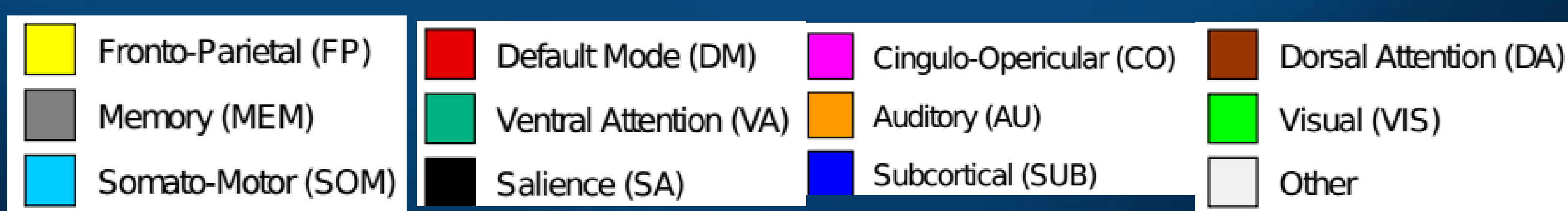
Right: 2-back connector hubs

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!

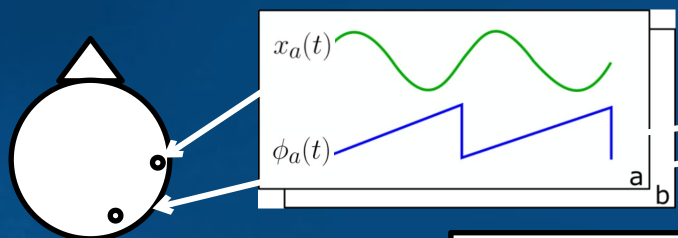




K. Finc et al, HBM (2017).

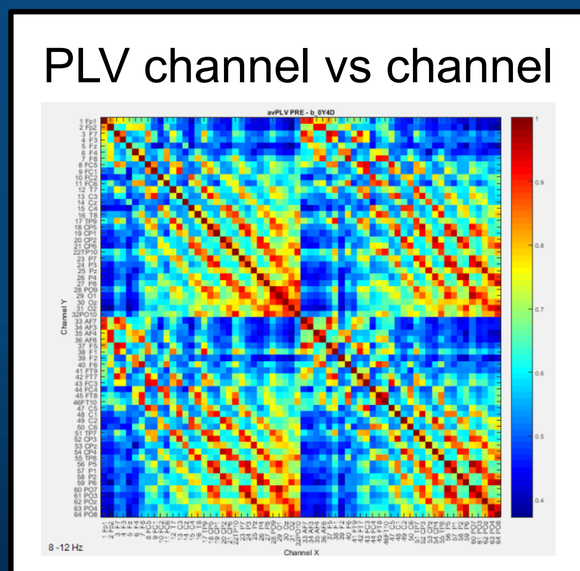
Functional connectivity changes

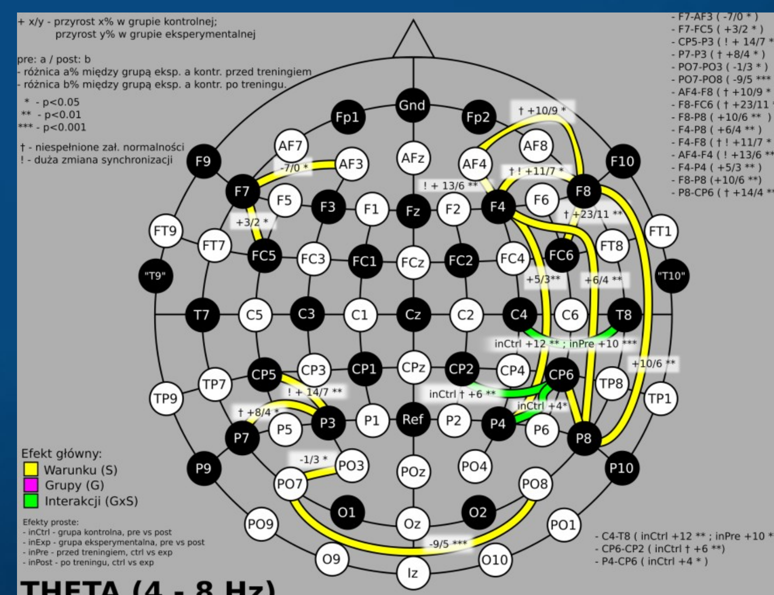
Influence of brain games on functional connectivity: **Phase Locking Value** (Burgess, 2013; Lachaux 1999), phase differences between signals measured at each electrode. PLV => synchronization maps, info flow.



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

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



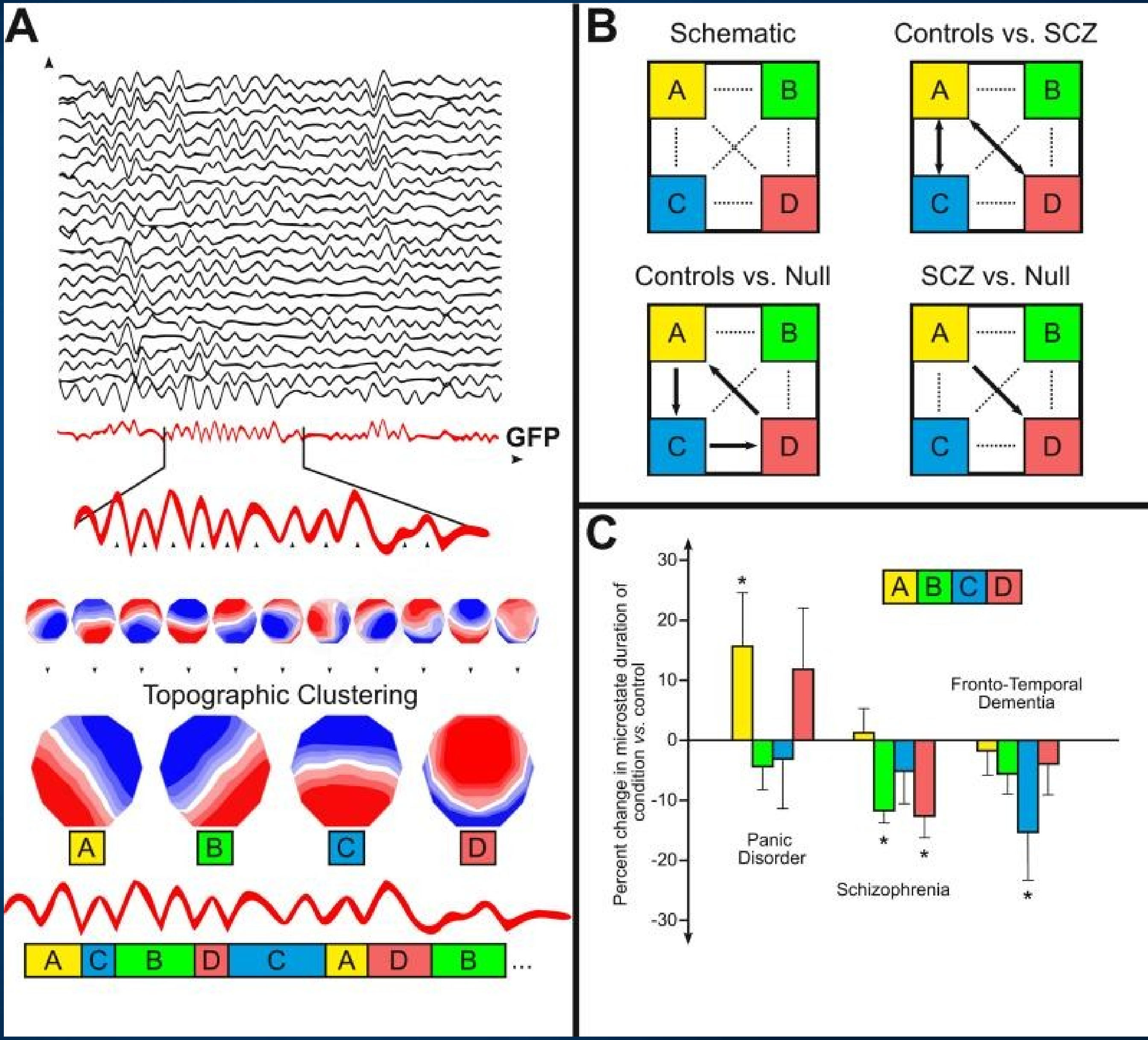


Microstates

Lehmann et al.
EEG microstate duration and syntax in acute, medication-naïve, first-episode schizophrenia: a multi-center study.
Psychiatry Research Neuroimaging, 2005

Khanna et al.
Microstates in Resting-State EEG: Current Status and Future Directions.
Neuroscience and Biobehavioral Reviews, 2015

Symbolic dynamics.



Model of reading & dyslexia

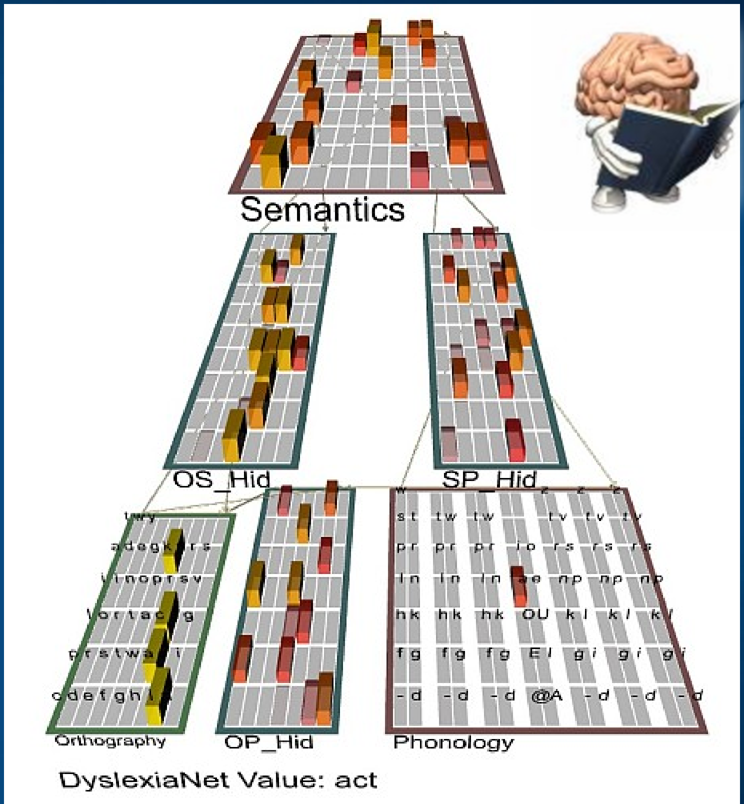
Emergent neural simulator:

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.

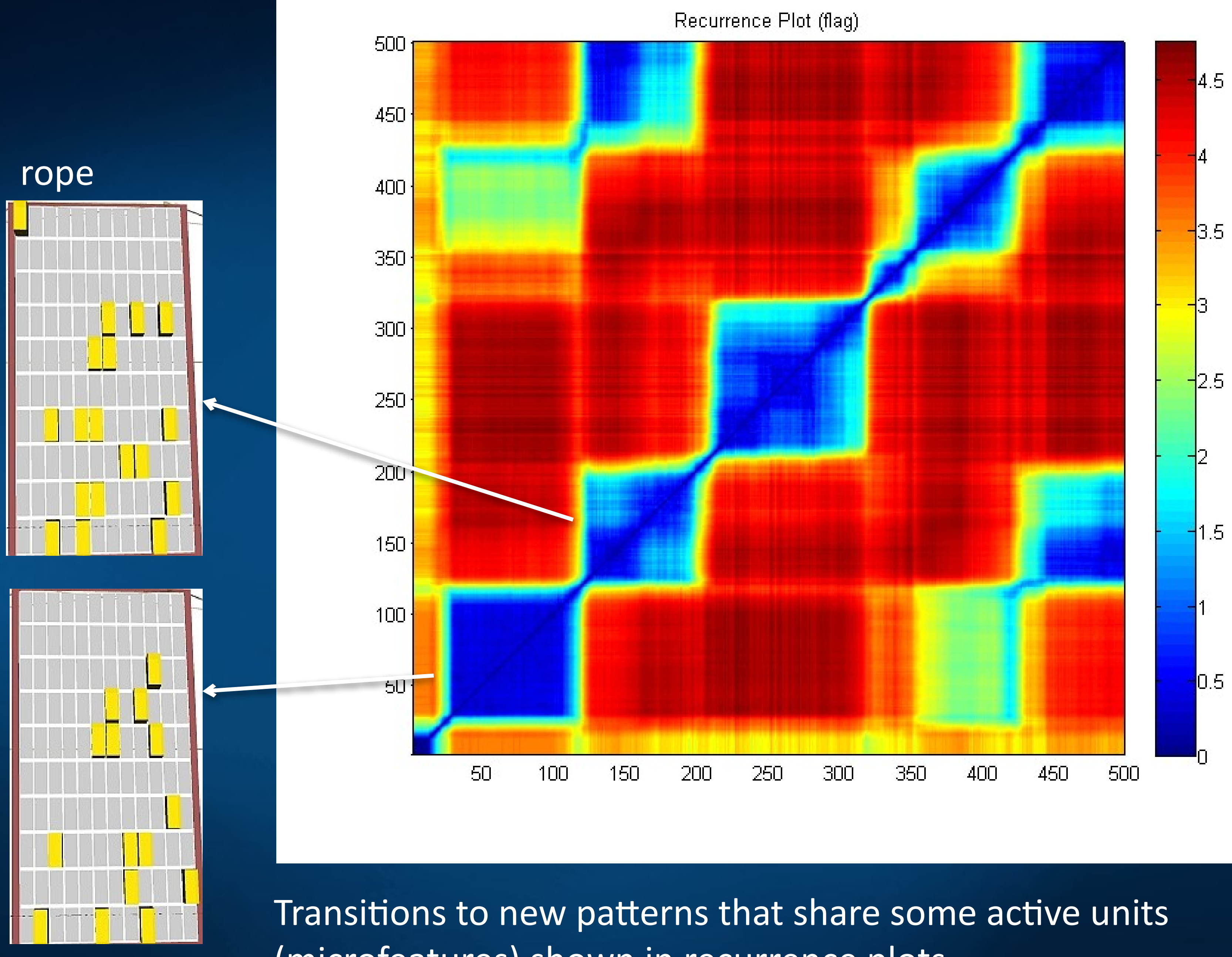
In the brain: microfeature=subnetwork. Hidden layers OS/OP/SP_Hid in between.



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

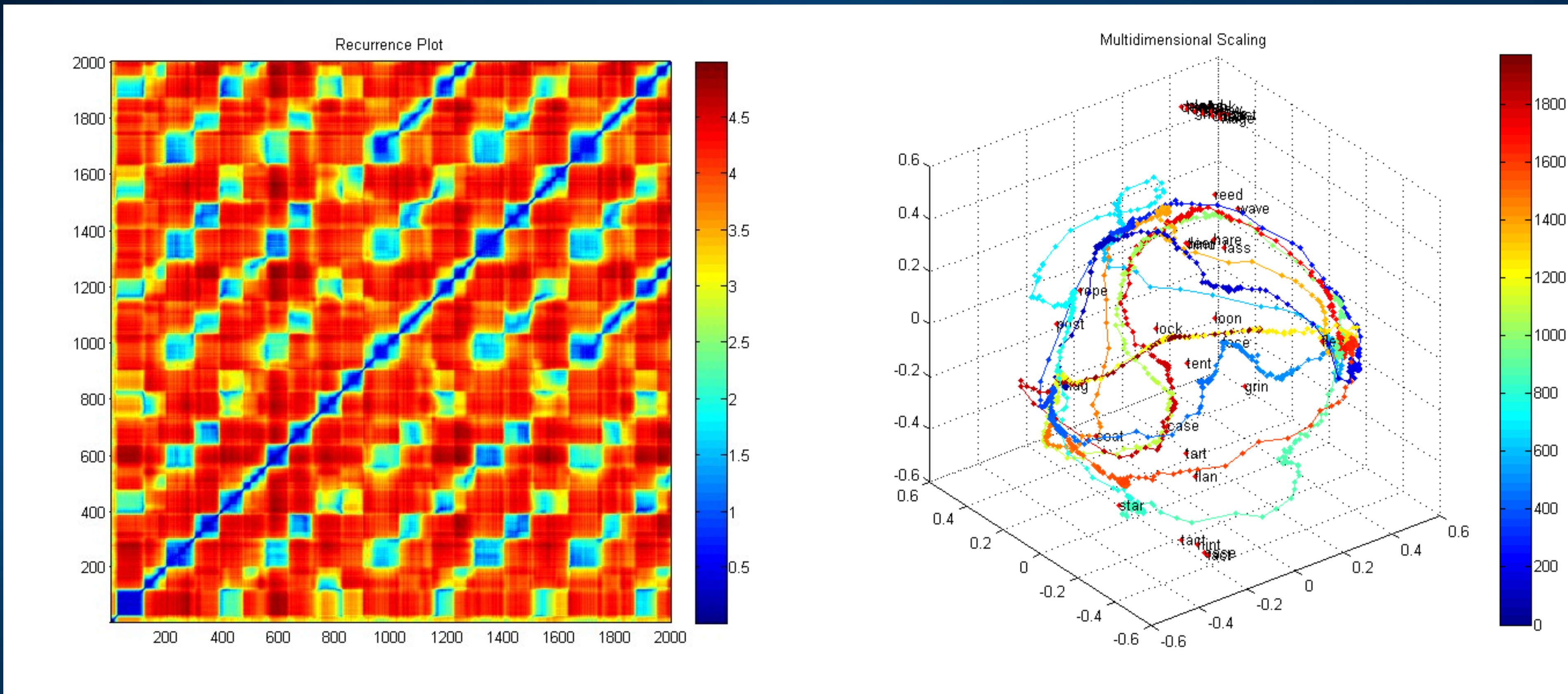
Fluctuations around final configuration = attractors representing concepts.

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



Transitions to new patterns that share some active units (microfeatures) shown in recurrence plots.

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/

EEG early ASD detection

Bosl, W. J., Tager-Flusberg, H., & Nelson, C. A. (2018). EEG Analytics for Early Detection of Autism Spectrum Disorder: A data-driven approach. Scientific Reports, 8(1), 6828.

EEG of 3 to 36-month old babies, 19 electrodes selected from 64 or 128.

Daubechies (DB4) wavelets transform EEG signal into 6 bands.

7 features from Recurrence Quantitative Analysis (RQA): RP entropy, recurrence rate, laminarity, repetition, max/mean line length, trapping time.

In addition sample entropy and Detrended Fluctuation Analysis was used.

Nonlinear features were computed from EEG signals and used as input to statistical learning methods. Prediction of the clinical diagnostic outcome of ASD or not ASD was highly accurate.

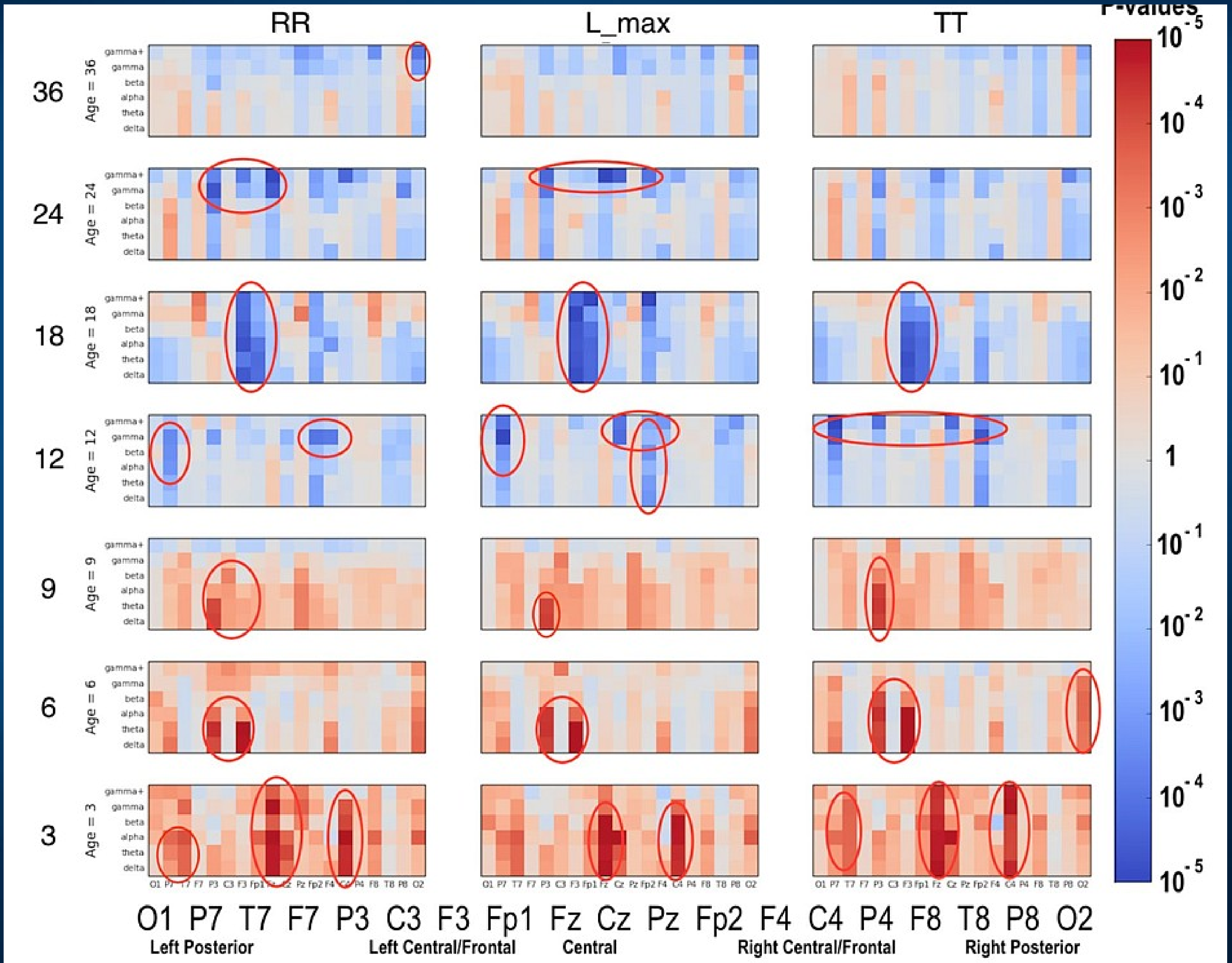
SVM classification with 9 features gave high specificity and sensitivity, exceeding 95% at some ages. Prediction using only EEG data taken as early as 3 months of age was strongly correlated with the actual measured scores.

ASD vs Low Risk Healthy

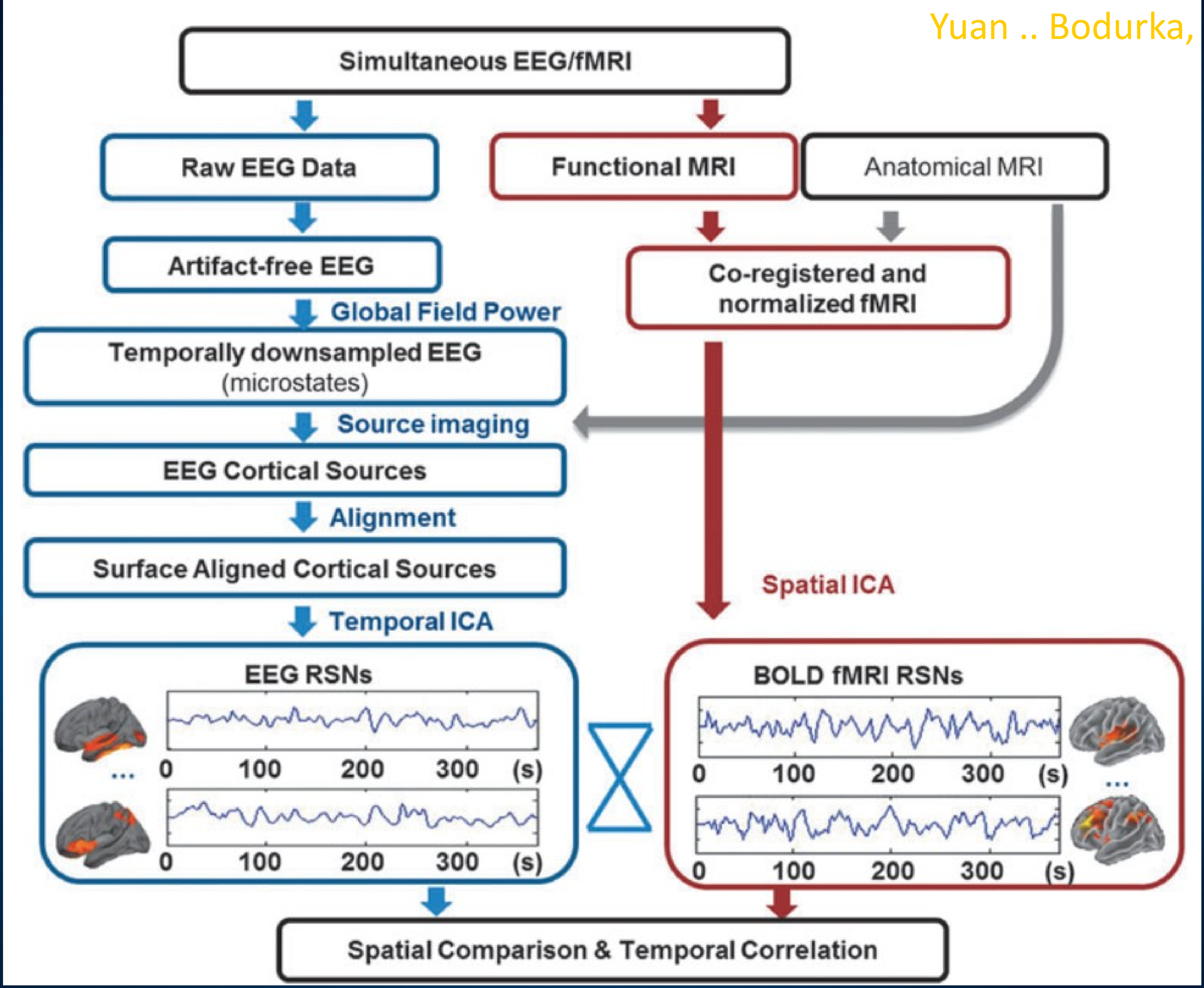
RR = recurrence rate

L_max = max line length, related to Lyapunov exponent

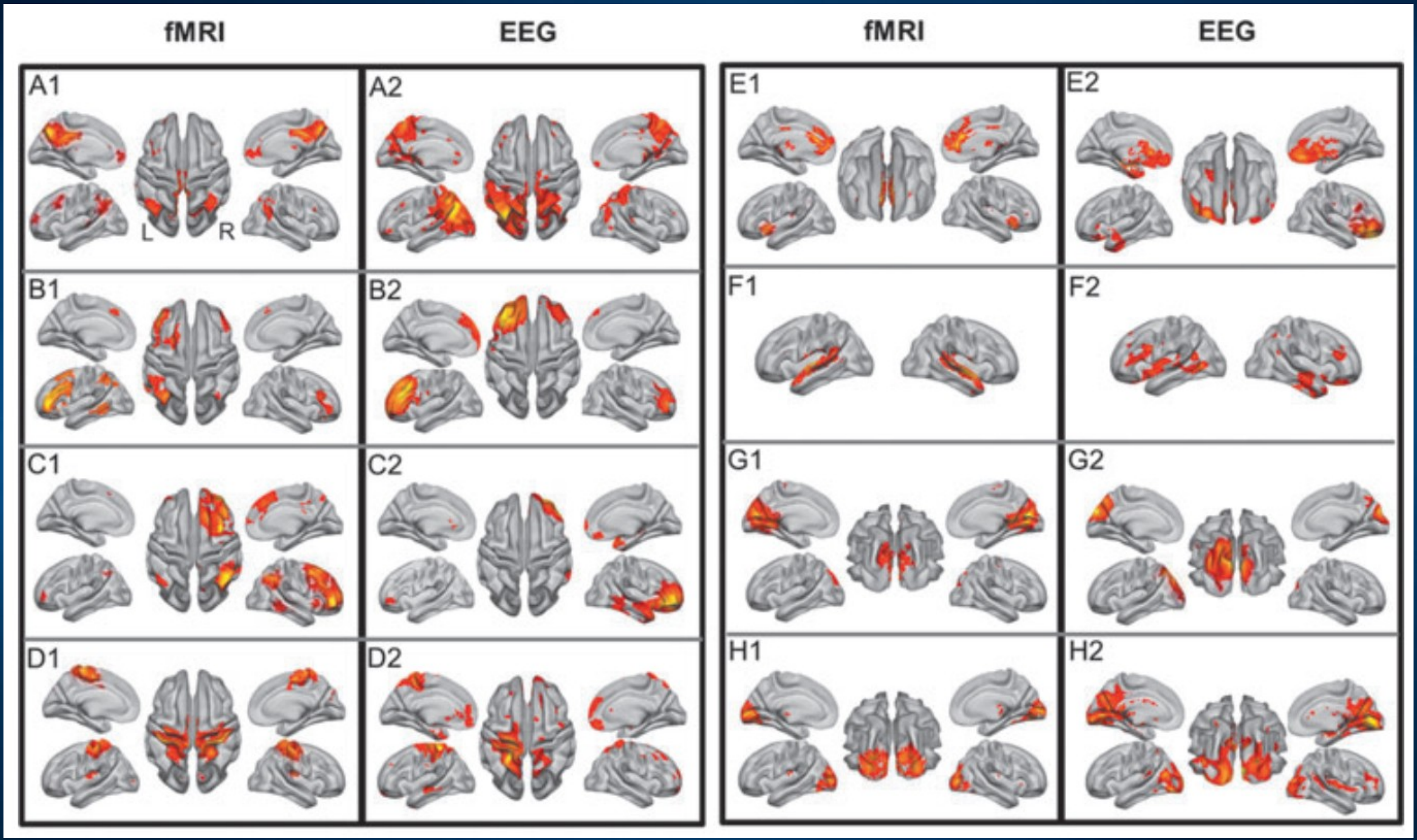
TT = trapping time



Yuan .. Bodurka, 2015

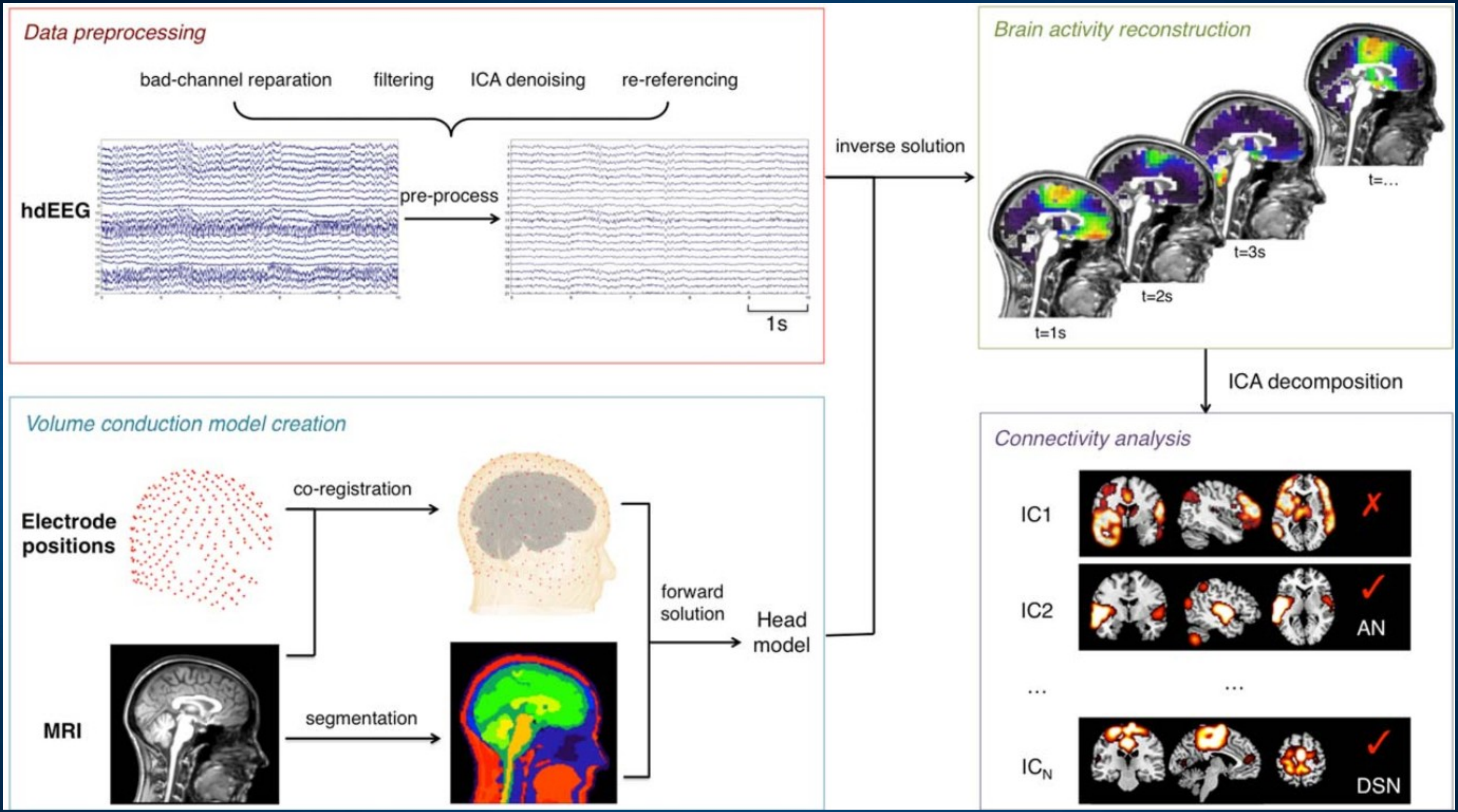


8 large networks from BOLD-EEG



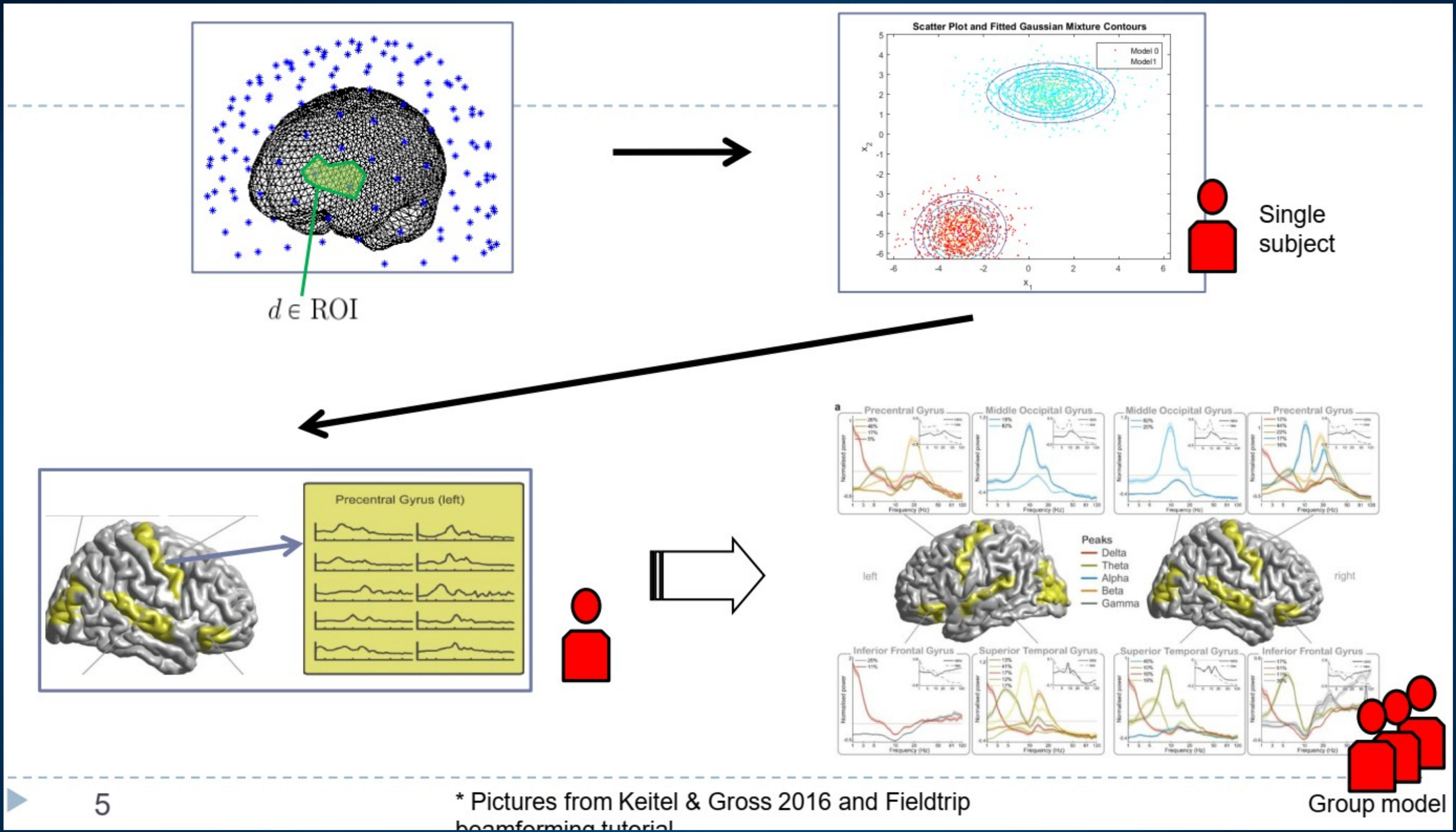
DMN, FP (frontoparietal)-left, right, sensorimotor, ex, control, auditory, visual (medial), (H) visual (lateral). Yuan … Bodurka (2015)

14 networks from BOLD-EEG



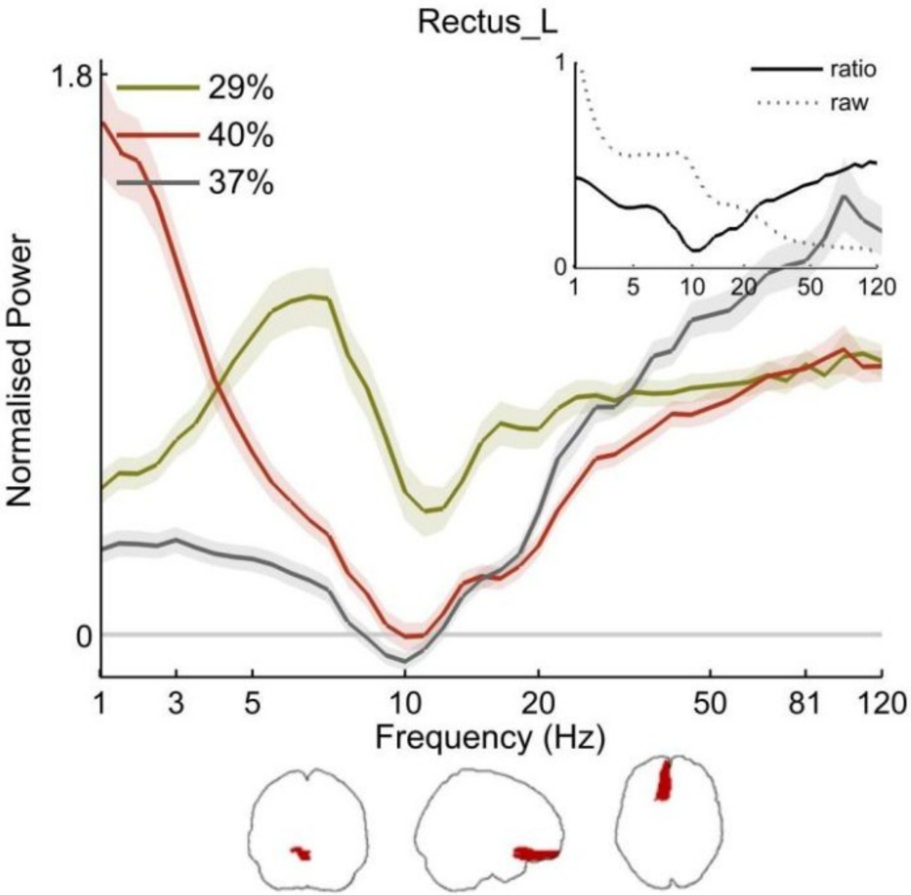
Liu et al. Detecting large-scale networks in the human brain. HBM (2017; 2018).

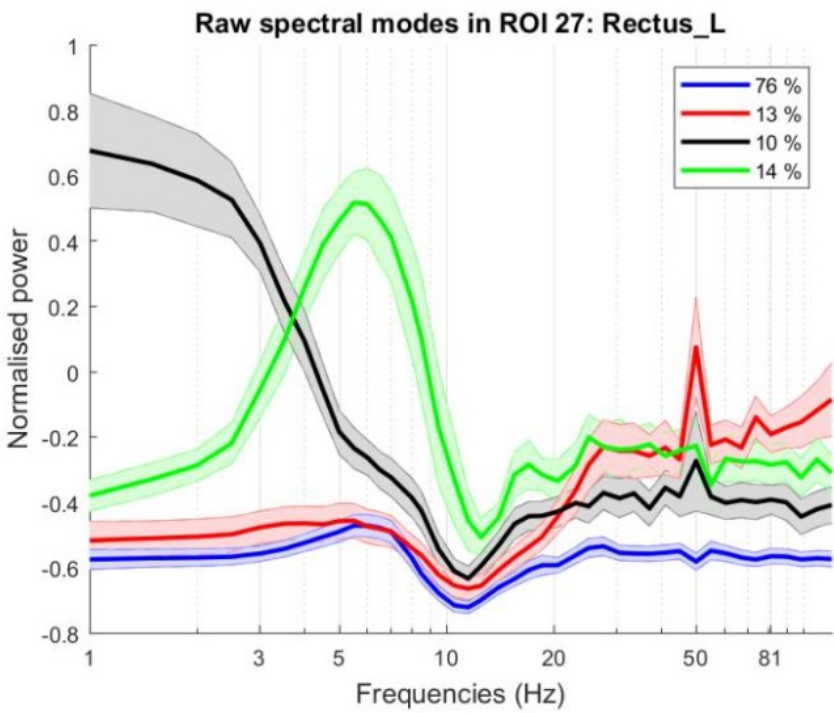
Spectral fingerprints



A. Keitel i J. Gross, „Individual human brain areas can be identified from their characteristic spectral activation fingerprints", *PLoS Biol* 14(6), e1002498, 2016

Spectral fingerprints

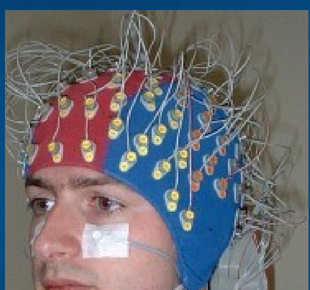


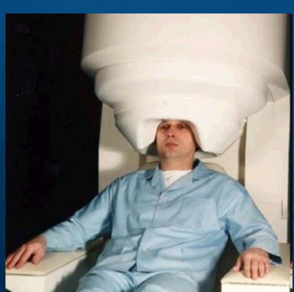


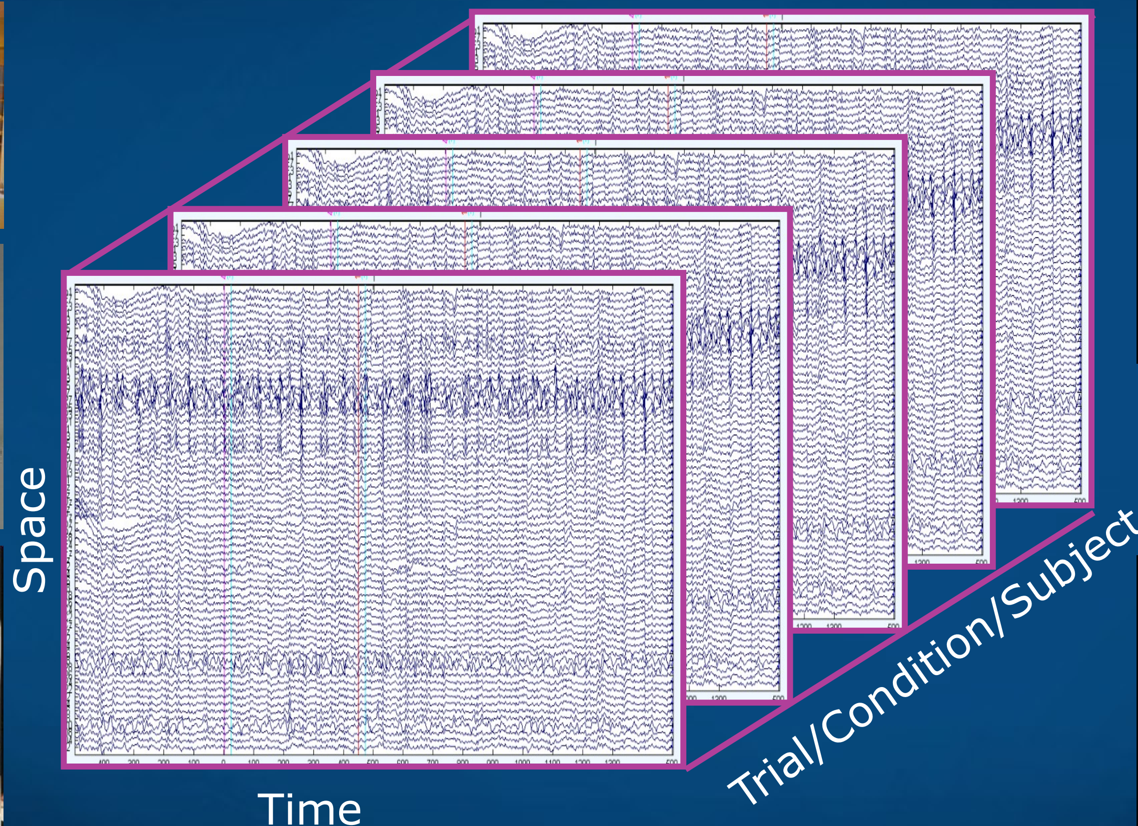
A. Keitel i J. Gross, „Individual human brain areas can be identified from their characteristic spectral activation fingerprints”, *PLoS Biol* 14, e1002498, 2016

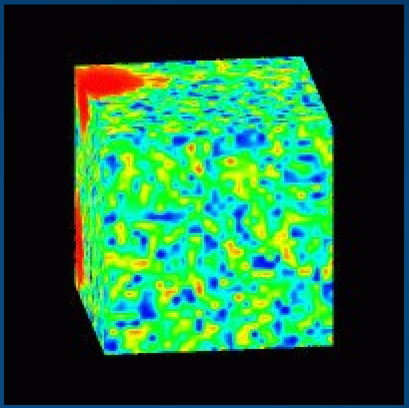
From Two-way to Multi-way Analysis
Integration and Fusion of Various Modalites
EEG+fNIRS +fMRI

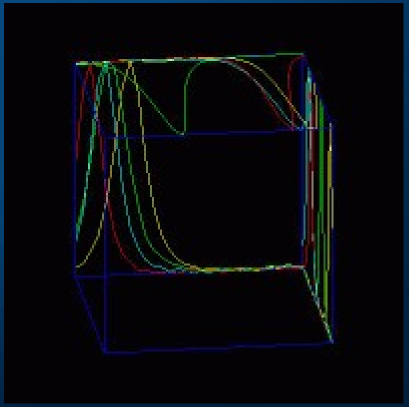
A. Cichocki Lab
RIKEN Brain Science Inst.





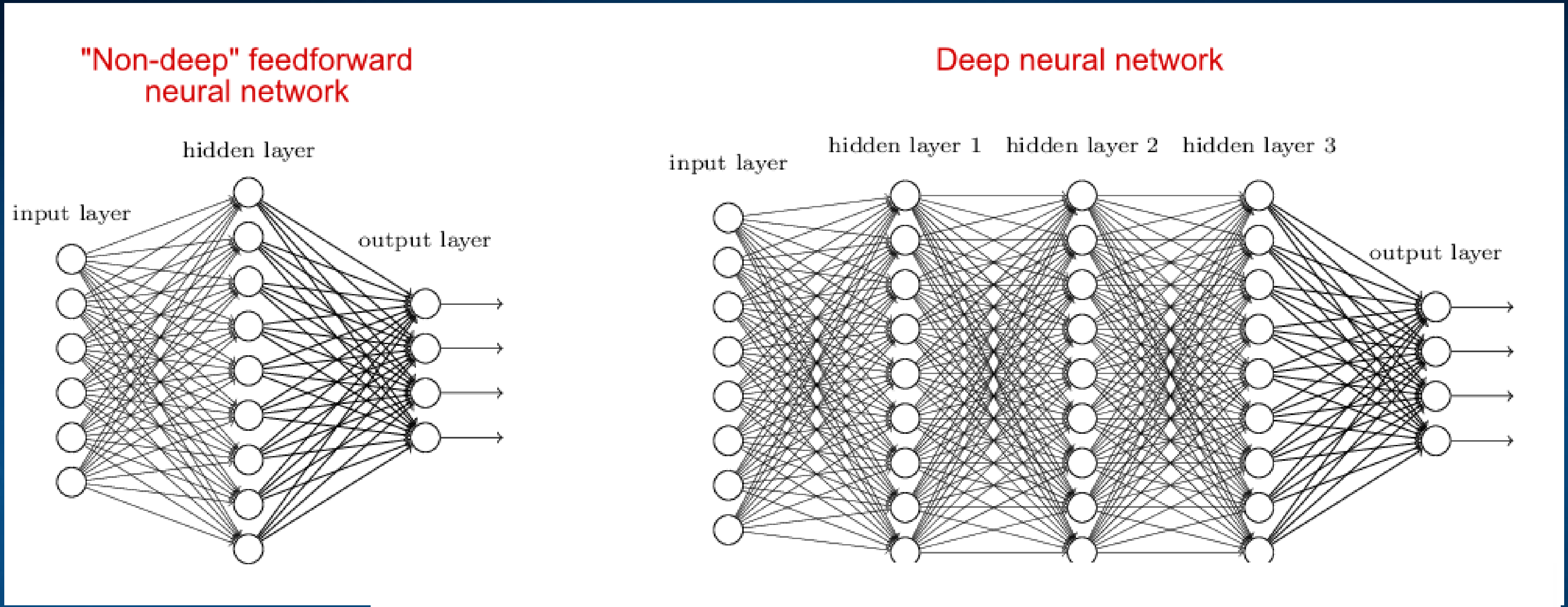


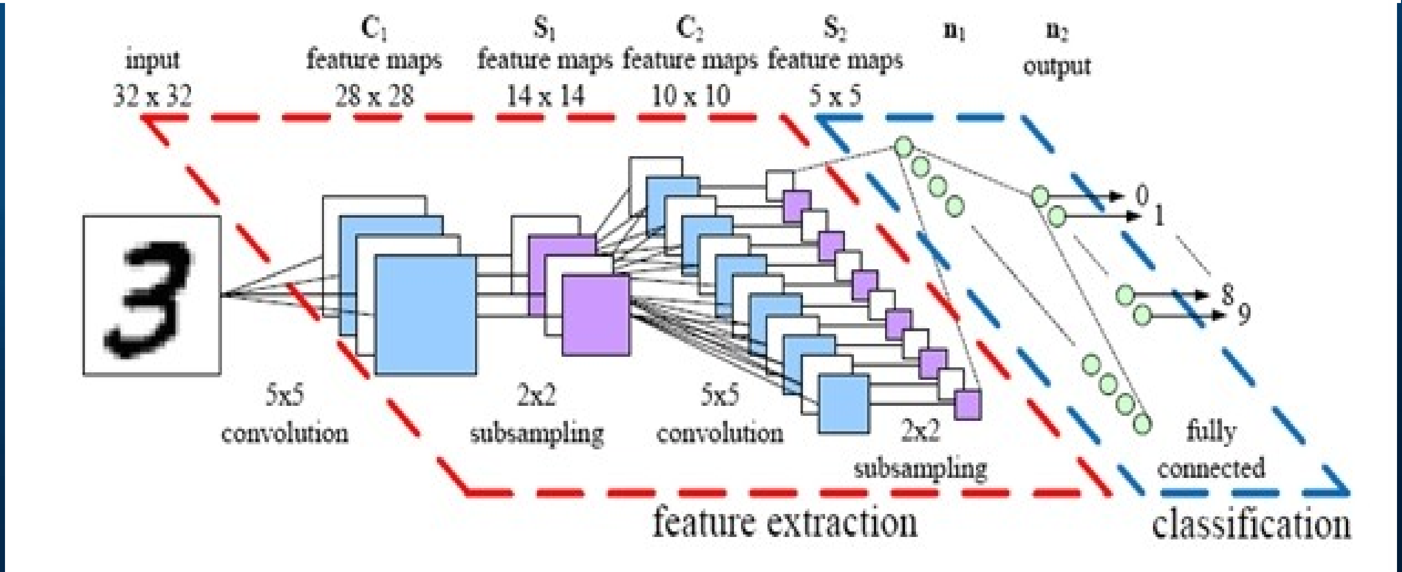




Exploratory and multi-way blind source separation and tensor factorizations: unsupervised learning methods and software to find the hidden causes & underlying hidden structure in the data.

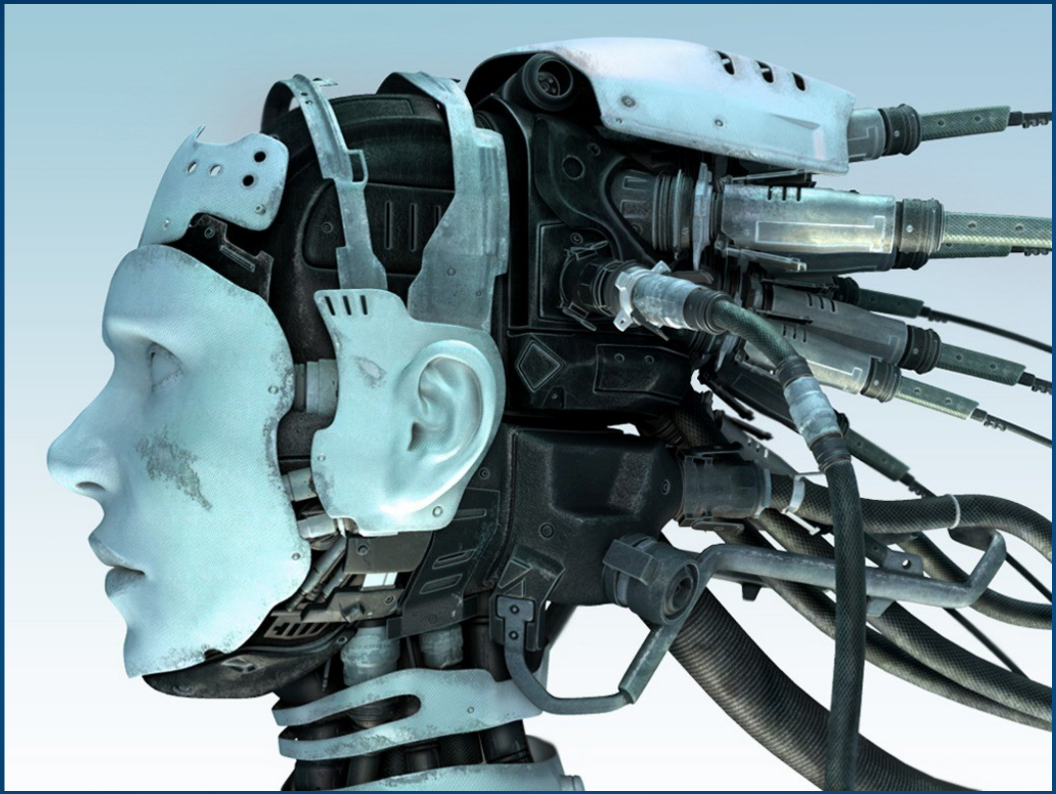
Tensorization of Convolutive Deep Learning NN





A. Cichocki Lab
RIKEN BSI

Neurocognitive technologies



There are about 100,000 cyborgs worldwide.
The human augmentation market may grow tenfold, to $2.3 billion, by 2025.

Bloomberg Businessweek 10/2018

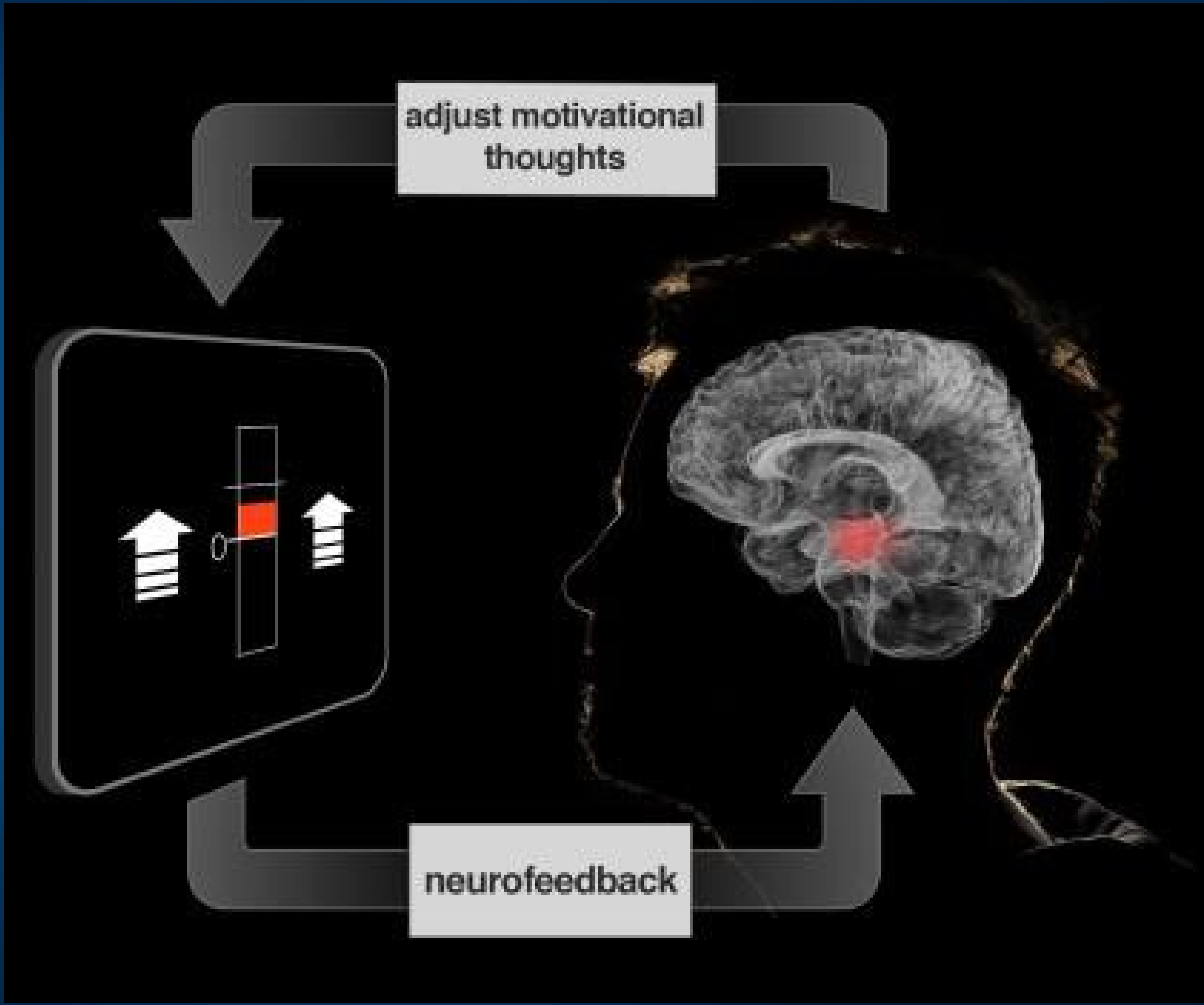
Neurofeedback: first BCI

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

W. Duch, Elektronika i stresy, Przekrój 1978!

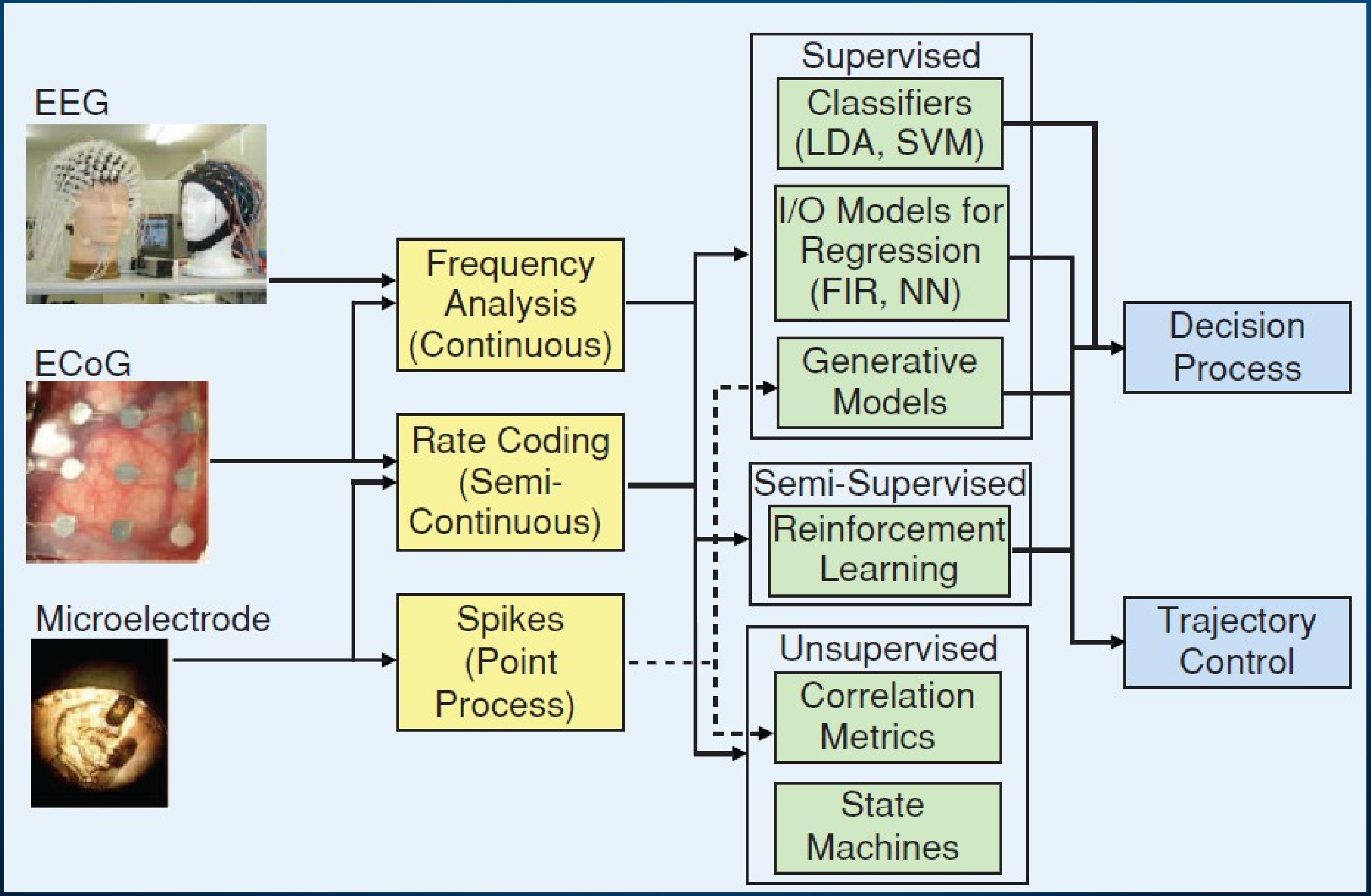
Critical review of existing literature shows that this is not effective.

New forms based on brain fingerprinting needed.

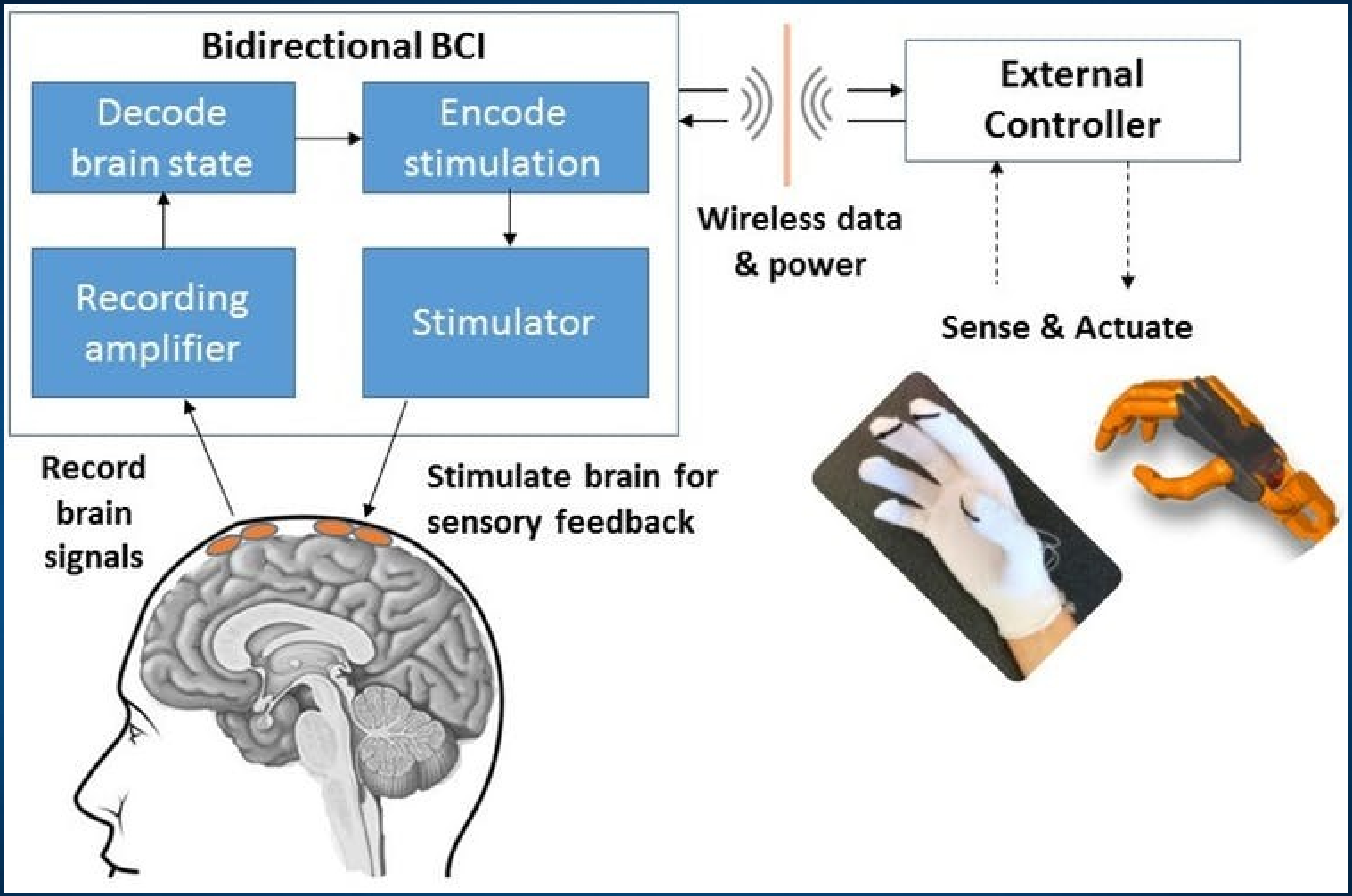


BCI: wire your brain …

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

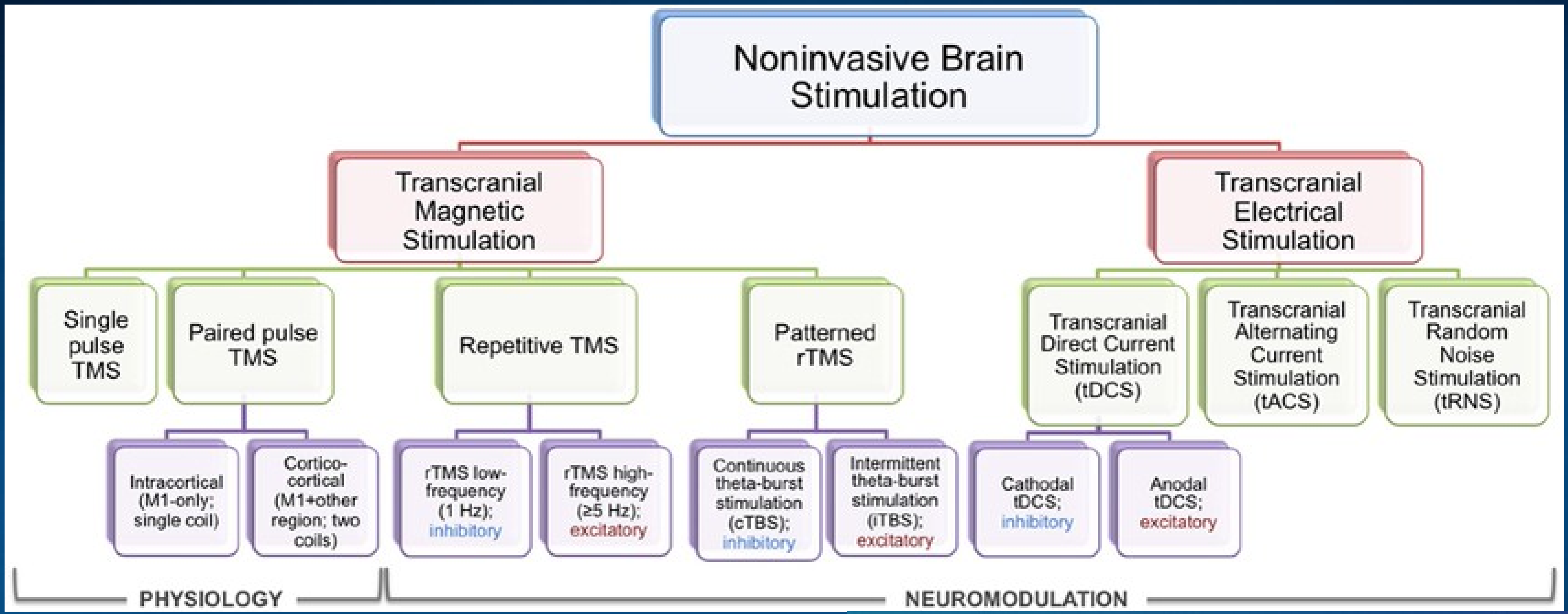


Brain-Computer-Brain Interfaces



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

Brain stimulation



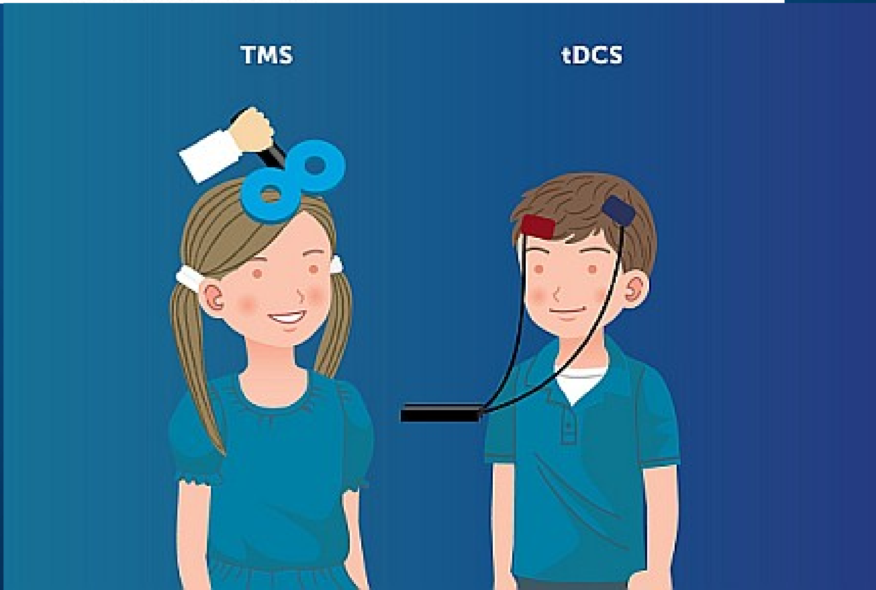
ECT – Electroconvulsive Therapy

VNS – Vagus Nerve Stimulation

Ultrasound, laser … stimulation.

Complex techniques, but portable phones are also complex.

TMS: 15 MW/pulse!



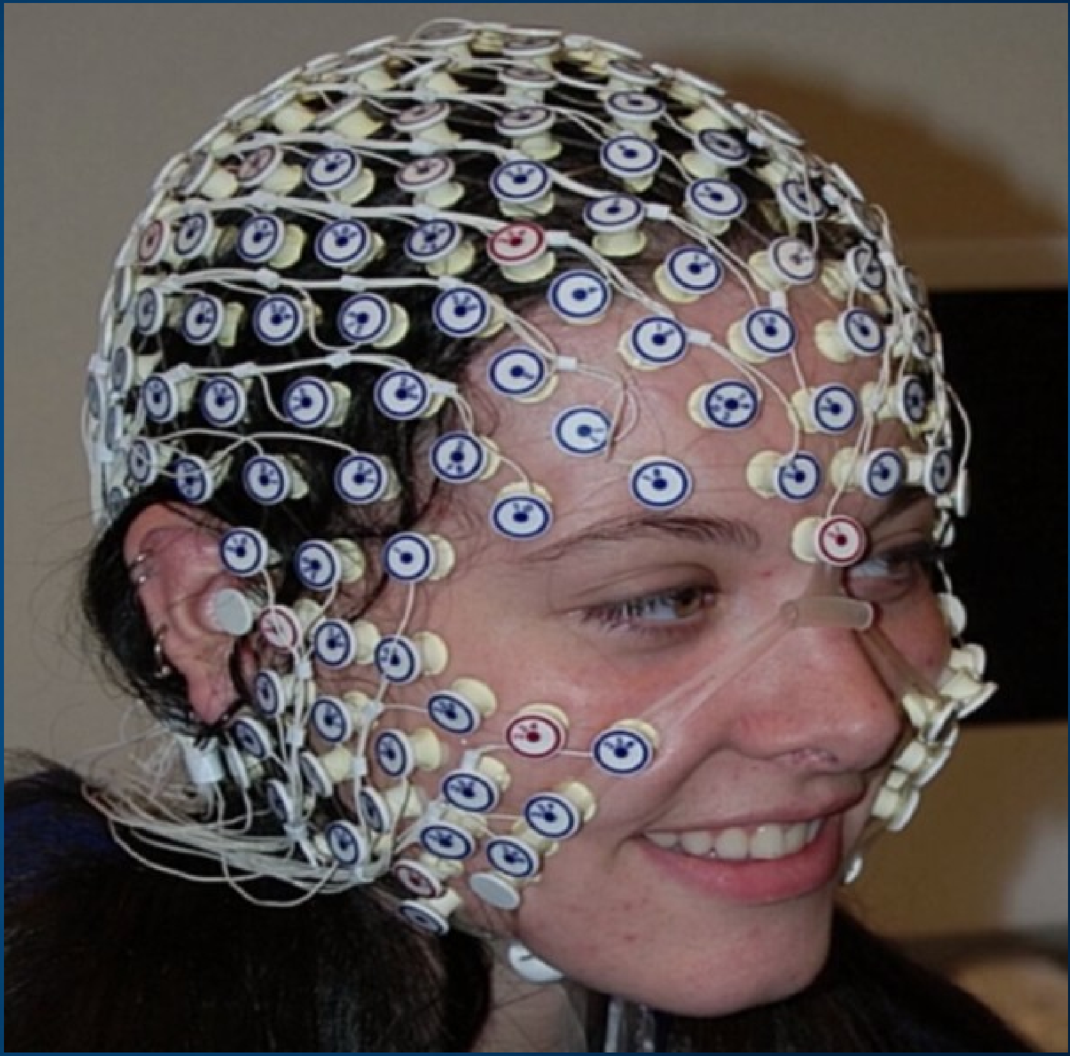
HD EEG/DCS?

EEG electrodes + DCS.

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

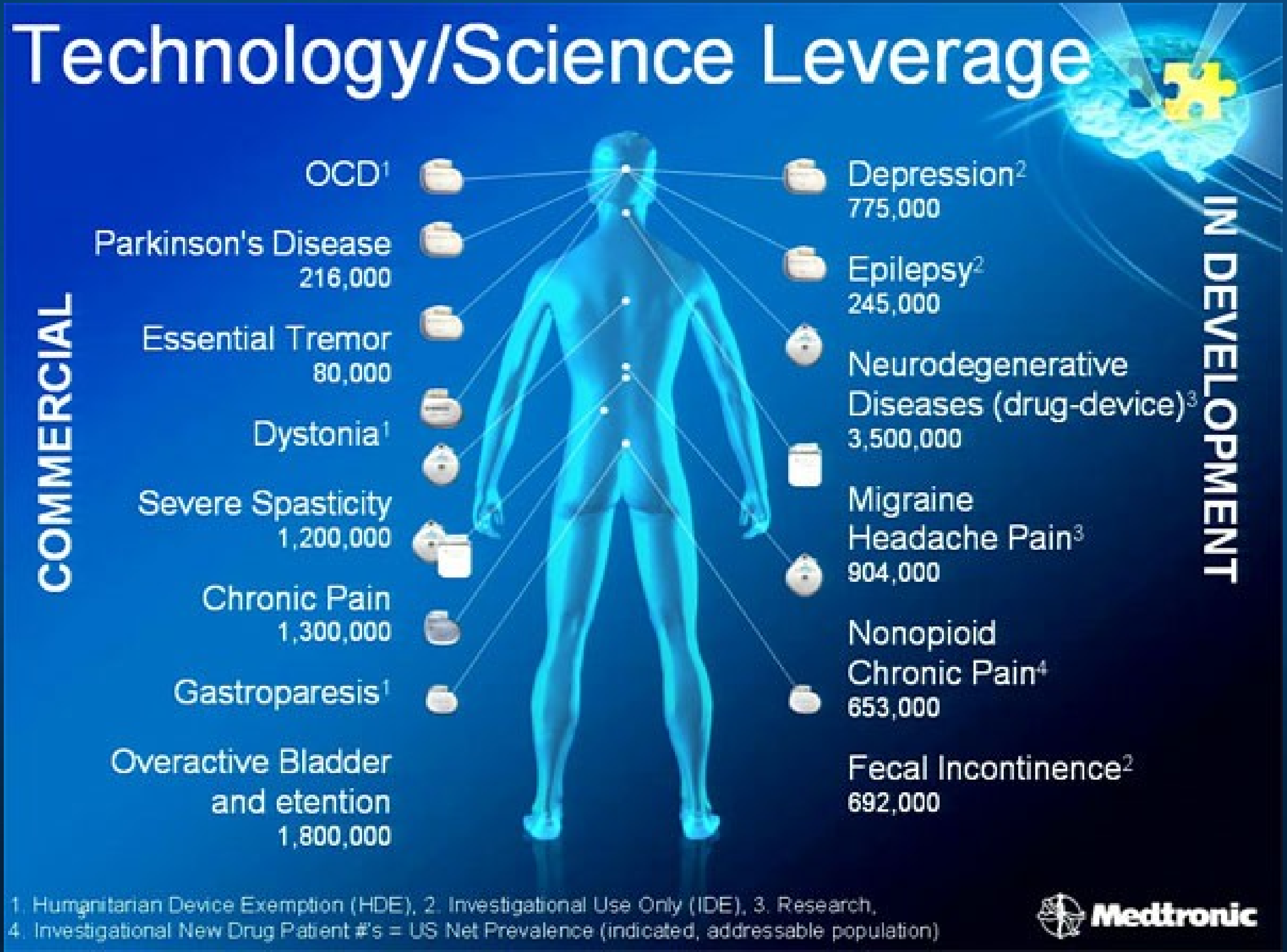
depression, neuro-plasticity, pain, psychosomatic disorders, teaching!

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

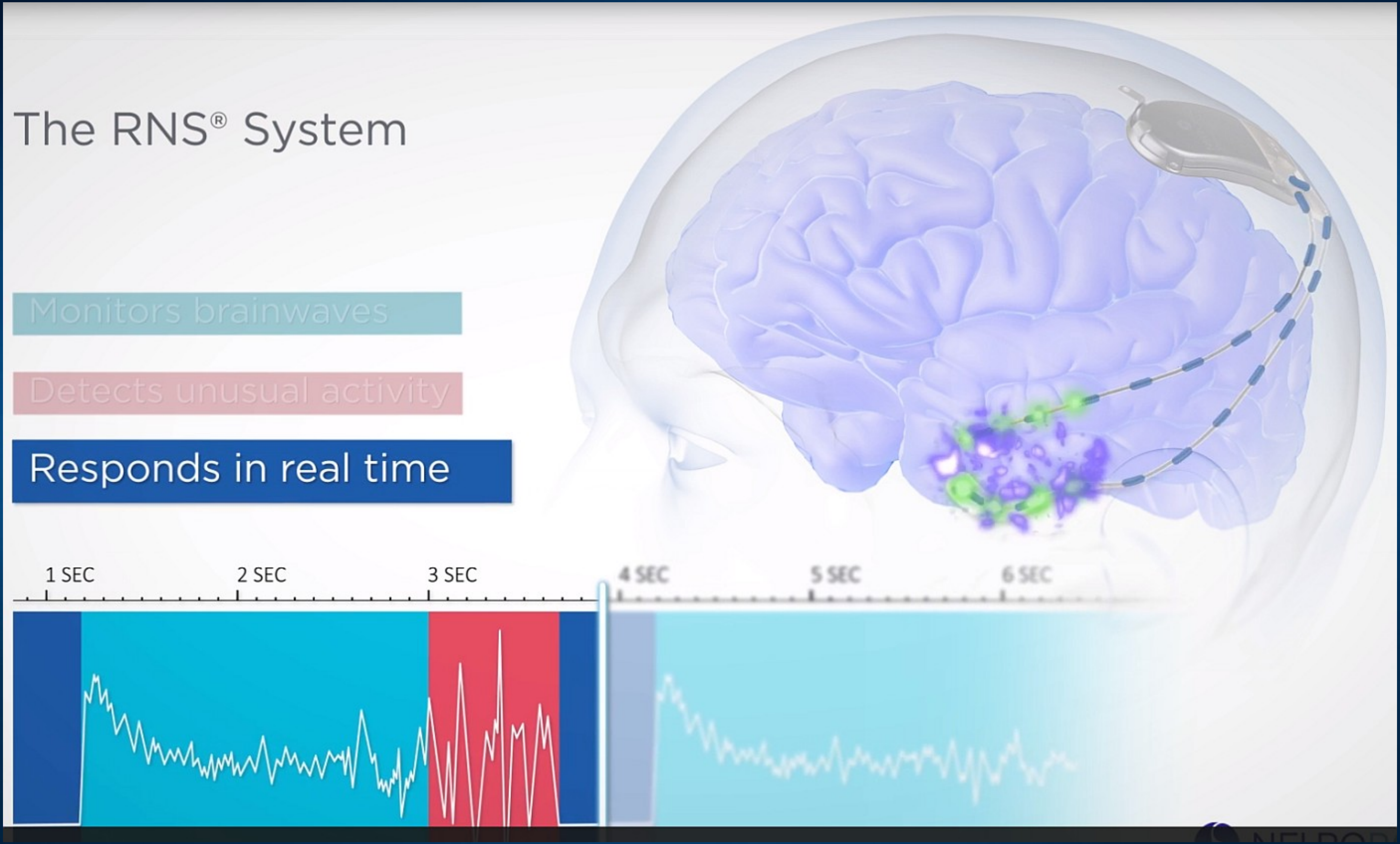


Neuromodulation

Cochlear implants are common, but deeper implants that stimulate or even replace some brain structures start to appear, not only for deficits at the level of perception, but to regulate neural processes.

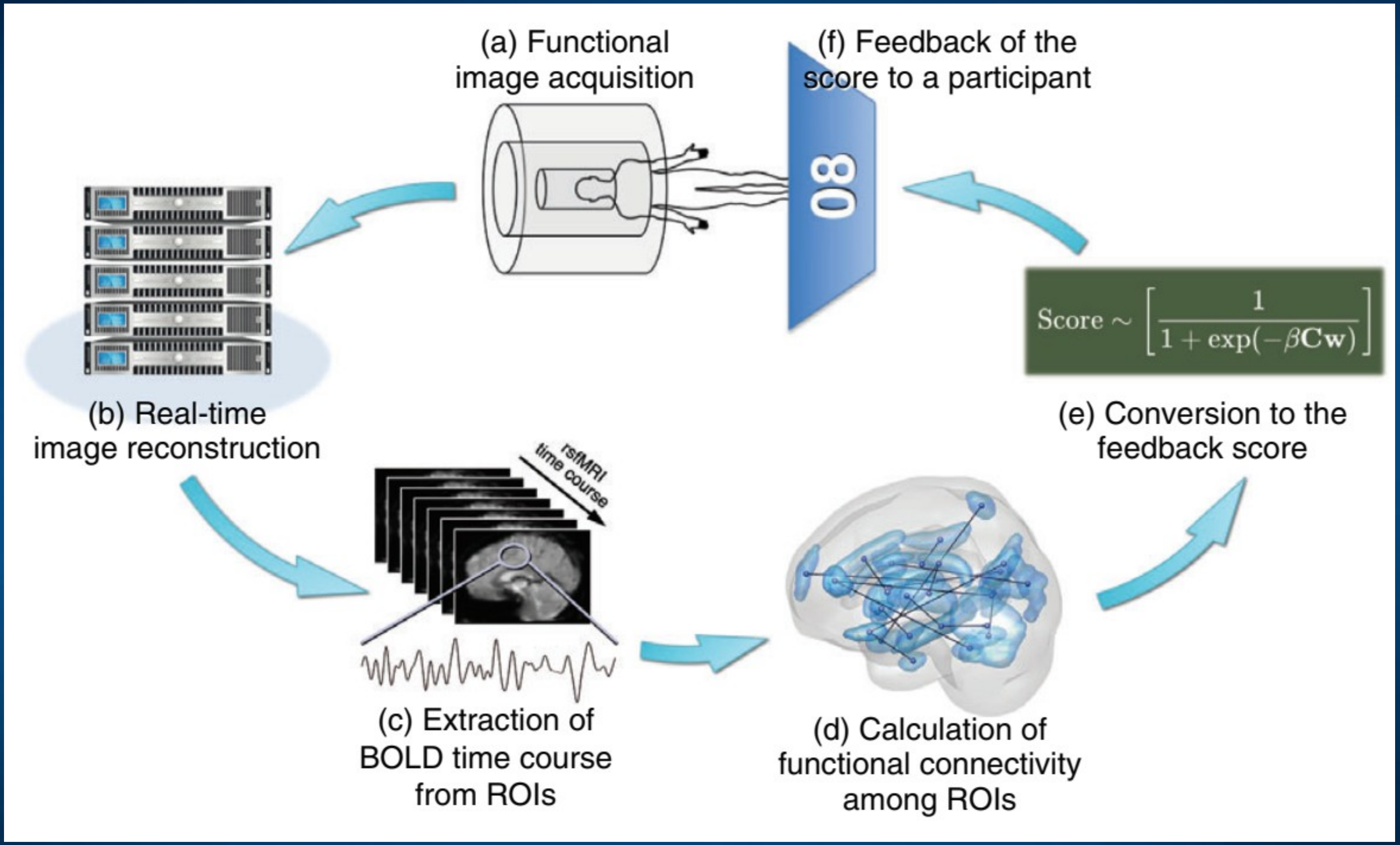


Epilepsy



1% of population suffers from epilepsy, if pharmacology does not help neurostimulation based on close loop may help – RNS system is now commercial.

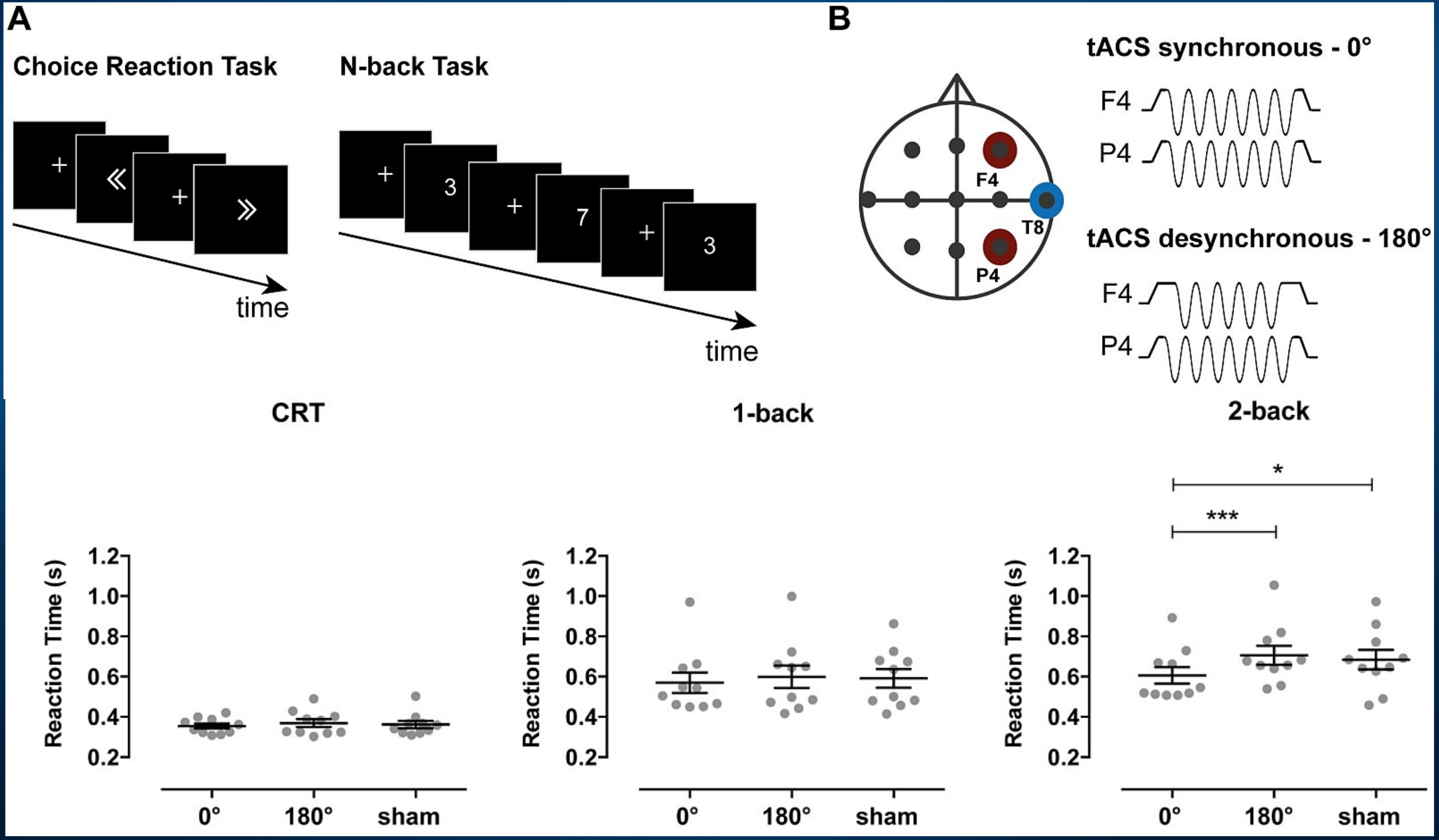
Neurofeedback may repair network?



Megumi F, Yamashita A, Kawato M, Imamizu H. Functional MRI neurofeedback training on connectivity between two regions induces long-lasting changes in intrinsic functional network. *Front. Hum. Neurosci.* 2015; **9**: 160.

Synchronize PFC/PC

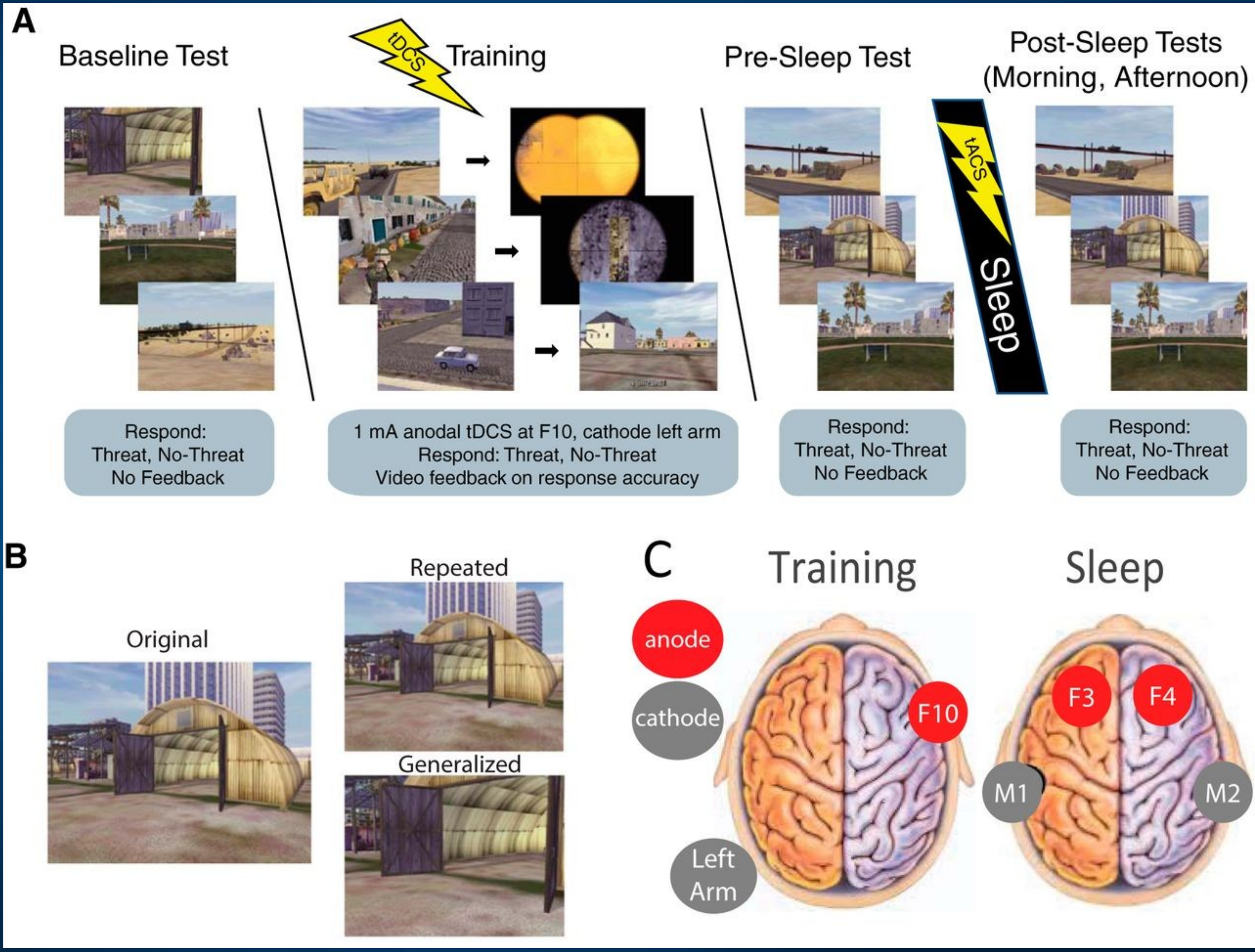
Violante, I.R. et al. Externally induced frontoparietal synchronization modulates network dynamics and enhances working memory performance. ELife, 6 (2017).



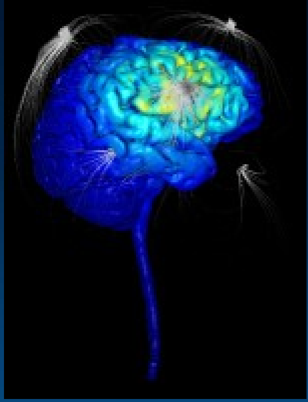
BCBI for skills/memory training

N. Ketz et al.,
J. Neuroscience
8 (33) 2018

Closed-Loop Slow-Wave tACS Improves Sleep-Dependent Long-Term Memory Generalization by Modulating Endogenous Oscillations



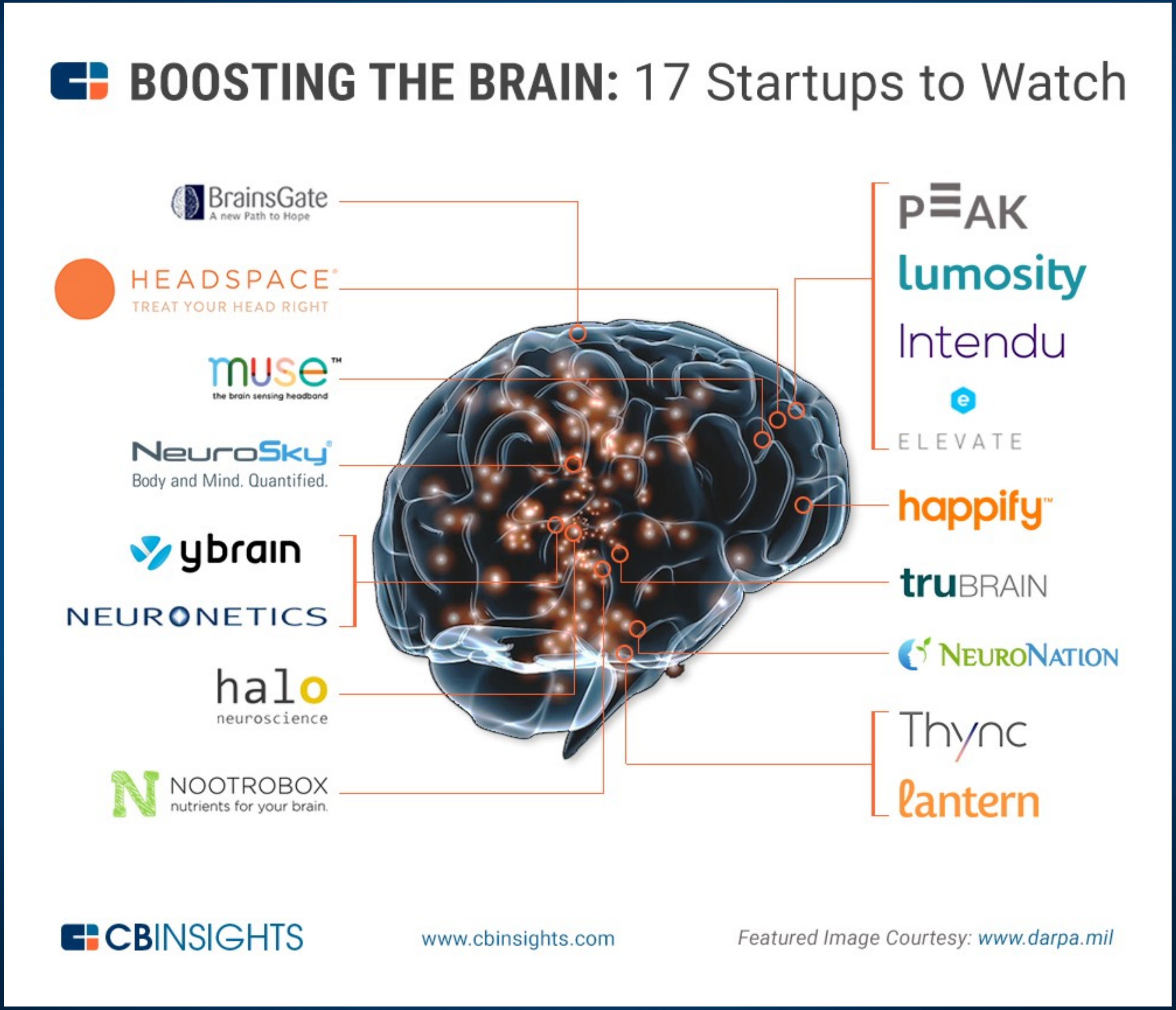
BCBI for learning



Your brain knows better what is interesting than you do!
How to make this information consciously available?

1. Externally induced frontoparietal synchronization modulates network dynamics and enhances working memory performance (Violante 2017).
2. Natural brain-information interfaces: recommending information by **relevance inferred from human brain signals** (Eugster et al. 2016).
3. **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.
4. **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.

Startups around the world



Neuro-relax

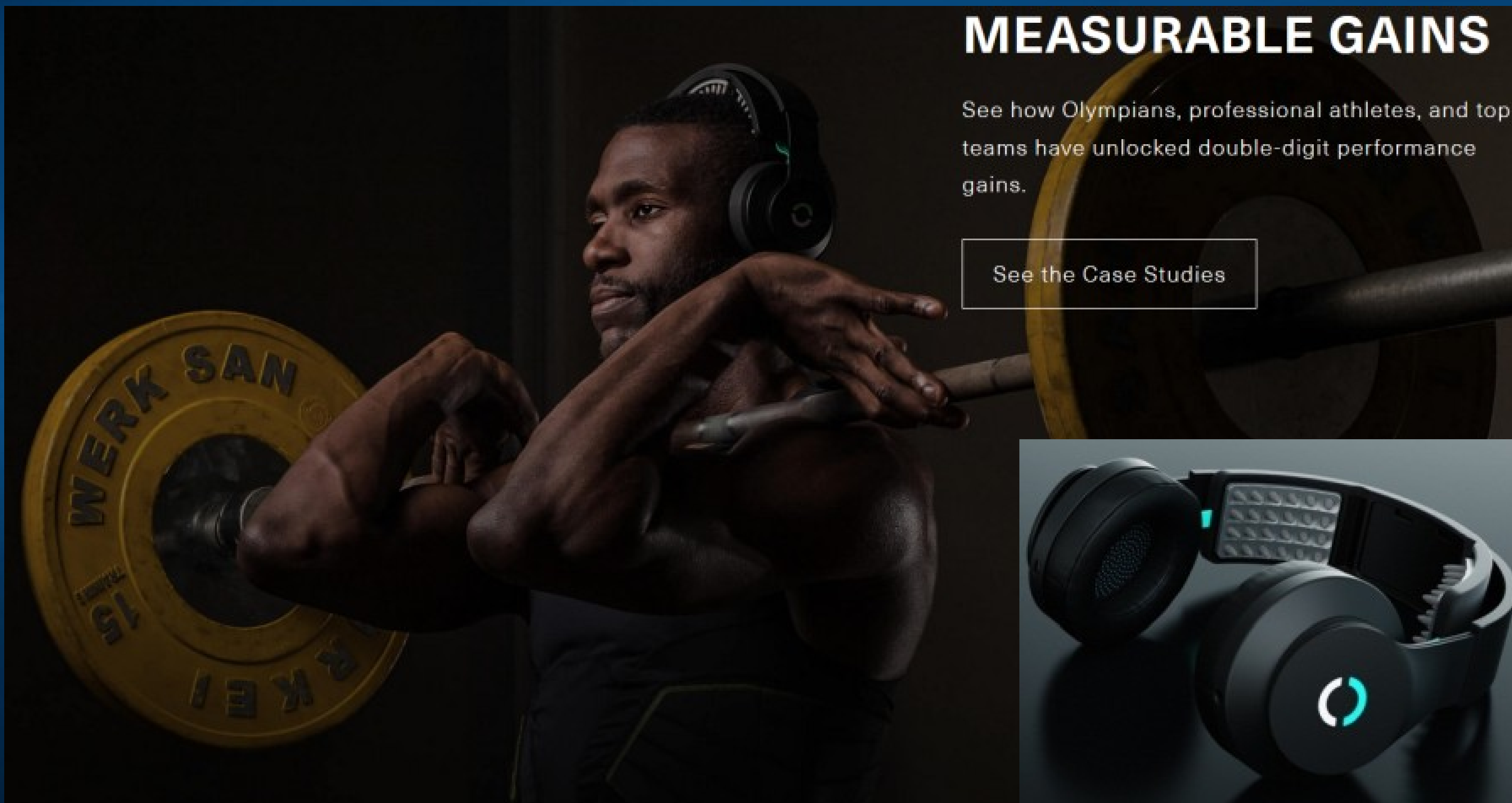
Sounds and music may have arousing or relaxing effects.

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.

Military applications

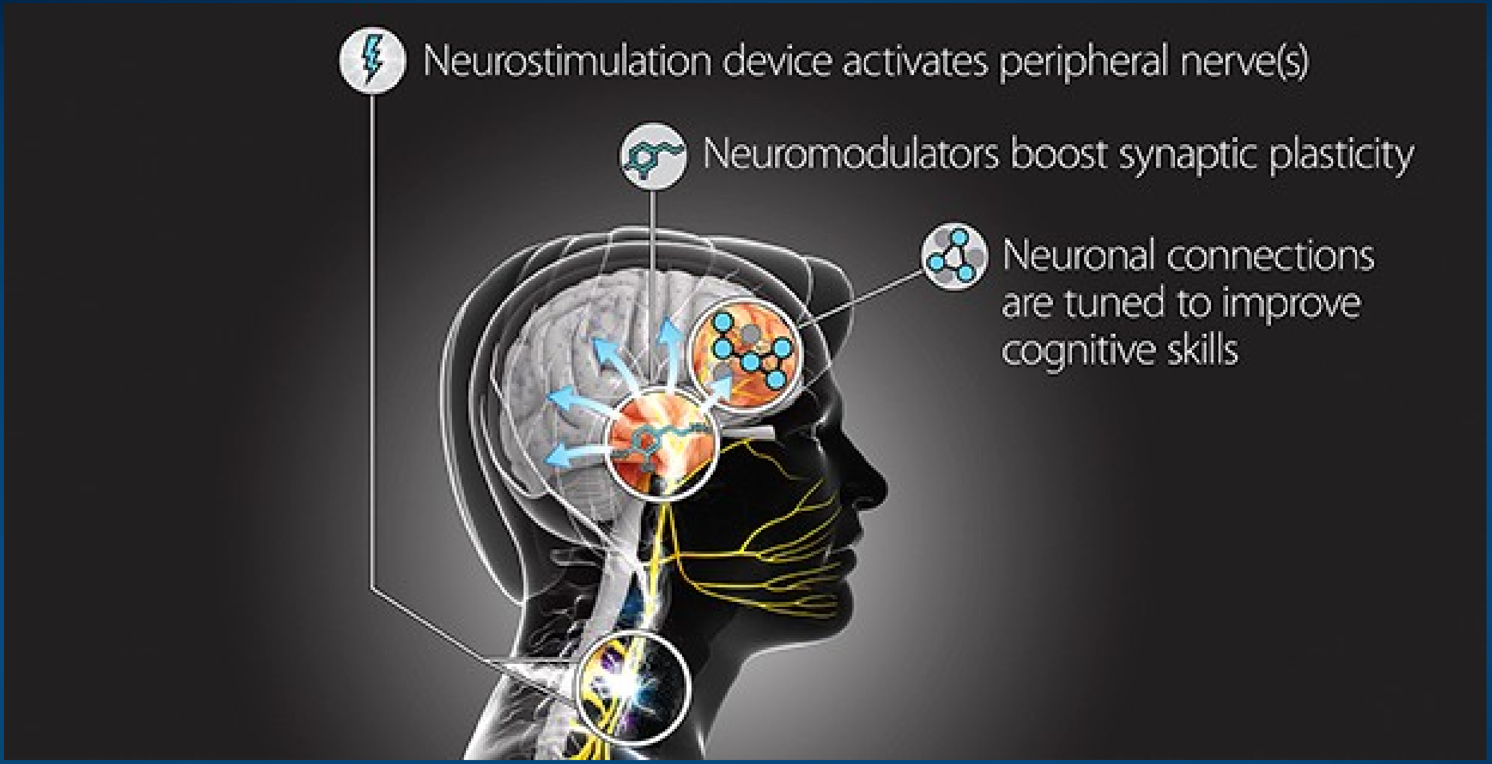
Engagement Skills Trainer (EST) procedures are used by USA army.

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, neurolace and nanowires much more.

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.

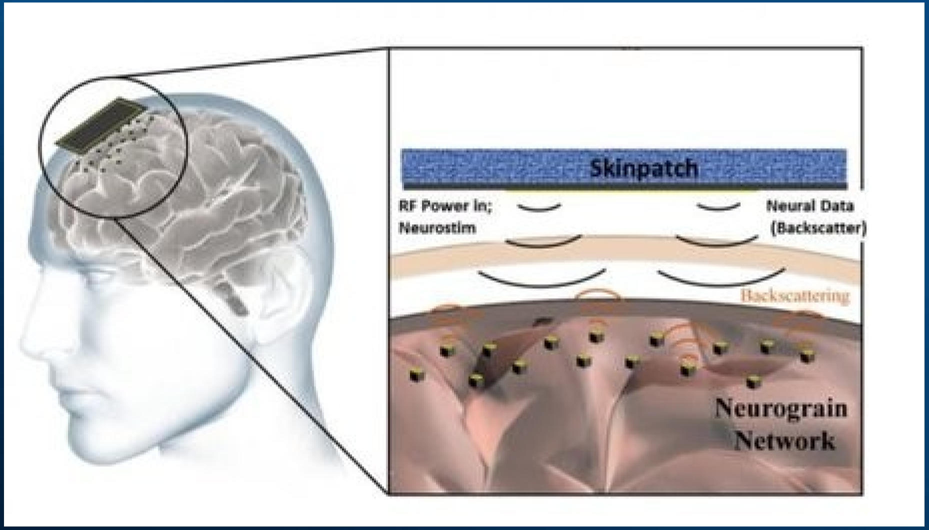
TNT could accelerate learning and reduce the time needed to train foreign language specialists, intelligence analysts, cryptographers, and others.

Million nanowires in your brain?

DARPA (2016): **Neural Engineering System Design (NESD)**
Interface that reads impulses of 10^6 neurons, injecting currents to 10^5 neurons, and reading/activating 10^3 neurons.

DARPA Electrical Prescriptions (ElectRx) project enables "artificial modulation of peripheral nerves to restore healthy patterns of signaling in these neural circuits. ElectRx devices and therapeutic systems under development are entering into clinical studies."

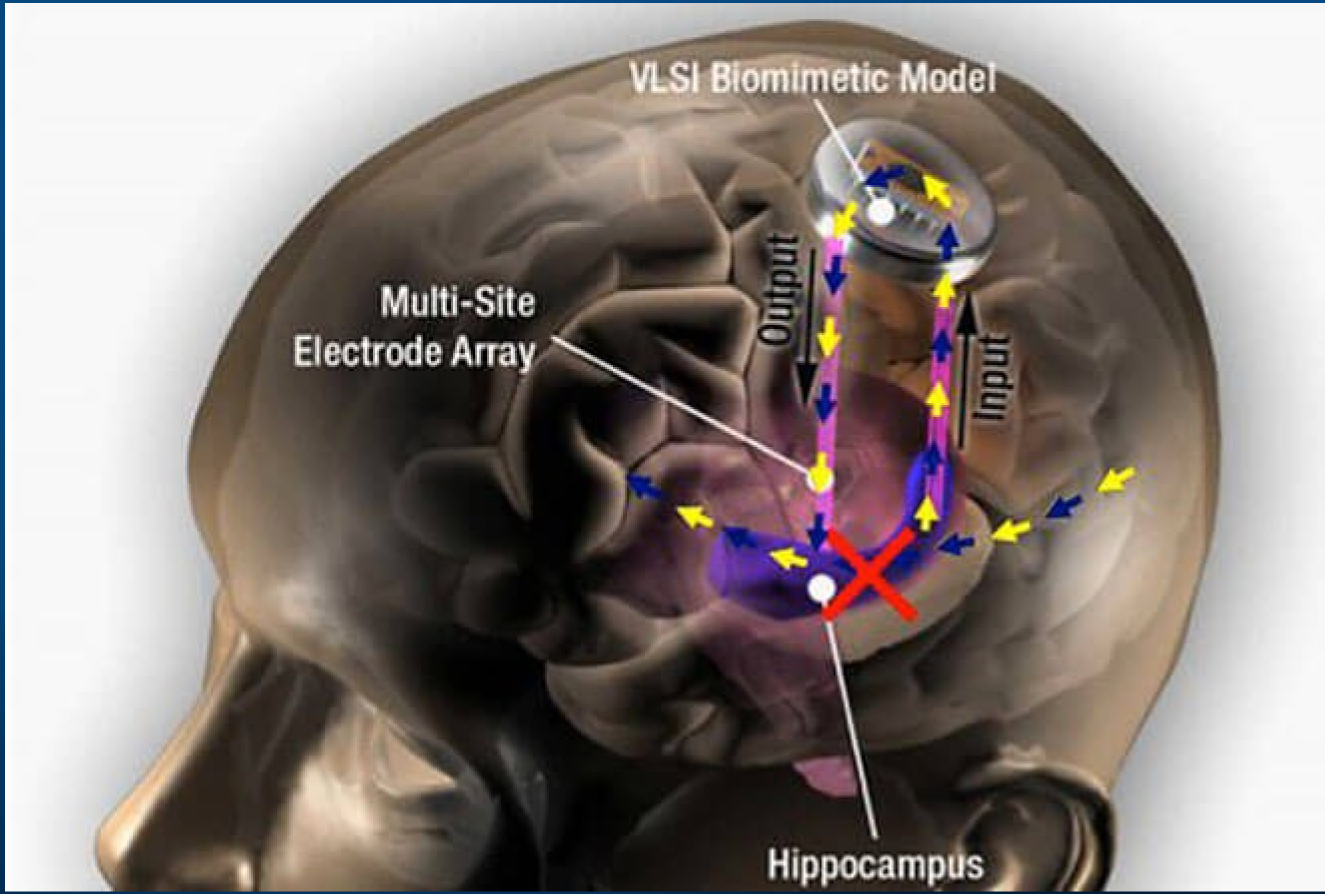
Neural lace i neural dust project for cortex stimulation.



Memory implants

Ted Berger (USC, Kernel): hippocampal neural prosthetics facilitate human memory encoding and recall using the patient's own hippocampal spatiotemporal neural codes. Tests on rats, monkeys and on people gave memory improvements on about 35% (J. Neural Engineering 15, 2018).

DARPA: Restoring Active Memory (RAM), new closed-loop, non-invasive systems that leverage the role of neural "replay" in the formation and recall of memory to help individuals better remember specific episodic events and learned skills.



Perspectives and benefits.

Expected benefits

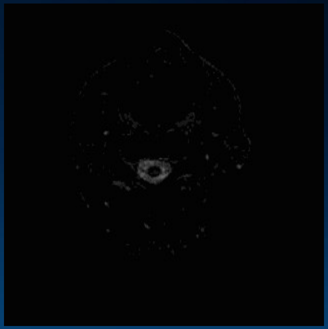
- **Monitoring development** of children and infants, perception, working memory, curiosity, unfolding full potential of children!
- Enabling early ASD diagnosis and other **developmental problems**.
- Precise **diagnosis** of various subtypes of mental disorders: organic problems, schizophrenia, epilepsy, learning disabilities, depression, anhedonia, mild cognitive impairment, Alzheimer etc,
  based on brain connectivity and functional large scale networks.
- Novel more effective forms of **neurofeedback**; for attention deficits, drug addiction, ASD, MCI and other problems.
- Nonpharmacological approaches to various forms of **pain management through neuromodulation**; distinguishing between organic, chronic, psychogenic and faking pain, and provide treatment based on neuromodulation.

Estimation: 27 B$ market for neural devices in 2025.

More benefits

- **Closed loop neurofeedback for neurorehabilitation**: discovering deficits in information flow in the brain, targeting neuroplasticity in specific brain areas to form new functional connections.
- Improvement in EEG-based **brain-computer interfaces**, new neurofedback/BCI in information retrieval and situation awareness.
- **Disorders of consciousness** – better diagnosis and communication with patients in coma.
- **Applications in education**: testing for problems such as dyslexia or dyscalculia, lack of musical imagery, objective assessment of learning outcomes and individual learning differences.
- **Memory improvement** through neuromodulation and in future deep brain stimulation.
- Neurocognitive technologies for general optimization of brain processes, for entertainment, games.

Strategic Questions



- Neurocognitive technologies are complex. Any volunteers?
- AI and neurocognitive informatics are **mutually beneficial**, and give a chance to build **artificial general human-level intelligent systems**, but only the best AI groups understand it and use inspirations from neuroscience.
- **Roadmap**: Brain neuroimaging ⇔ models of brain processes ⇔ links with AI mental models ⇔ closed loop BCBI for conscious control/brain optimization.
- **Neuromorphic hardware** with complexity beyond the human brain is coming and we should learn how to use it in practical applications.
- **Basic research**: methods for discovering brain fingerprints of cognitive activity, mapping between brain and mental states is our main goal.
- **Brain reading**, understanding neurodynamics and neurocognitive phenomics, are the key to self-regulation of brain functions, and therapeutic applications.
- Should we improve over our weaknesses in strategic areas, or focus on a few already developed AI research areas? **Can we afford ignorance**?
- With new global AI initiatives anything is possible!

Few Steps Towards Human-like Intelligence

IEEE Computational Intelligence Society Task Force (J. Mandziuk & W. Duch), **Towards Human-like Intelligence.**

IEEE SSCI 2018 Symposium on Computational Intelligence for Human-like Intelligence, Honolulu, HAWAII, USA, 27.11 –1.12.2017.
18-21.11.2018, Bengalur, India

AGI: conference, Journal of Artificial General Intelligence comments on Cognitive Architectures and Autonomy: A Comparative Review (eds. Tan, Franklin, Duch).

BICA: Annual International Conf. on Biologically Inspired Cognitive Architectures, 8rd Annual Meeting of the BICA Society, Moscow, August 1-5, 2017

Brain-Mind Institute Schools, International Conference on Brain-Mind (ICBM) and Brain-Mind Magazine (Juyang Weng, Michigan SU).

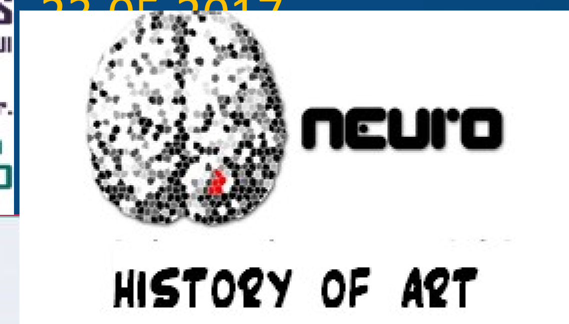
Soul or brain: what makes us human?
Interdisciplinary Workshop with theologians,
Toruń 19-21.10.2016

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

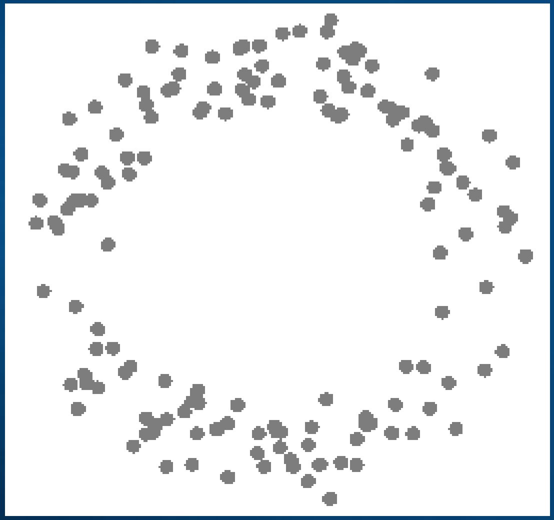
Disorders of consciousness

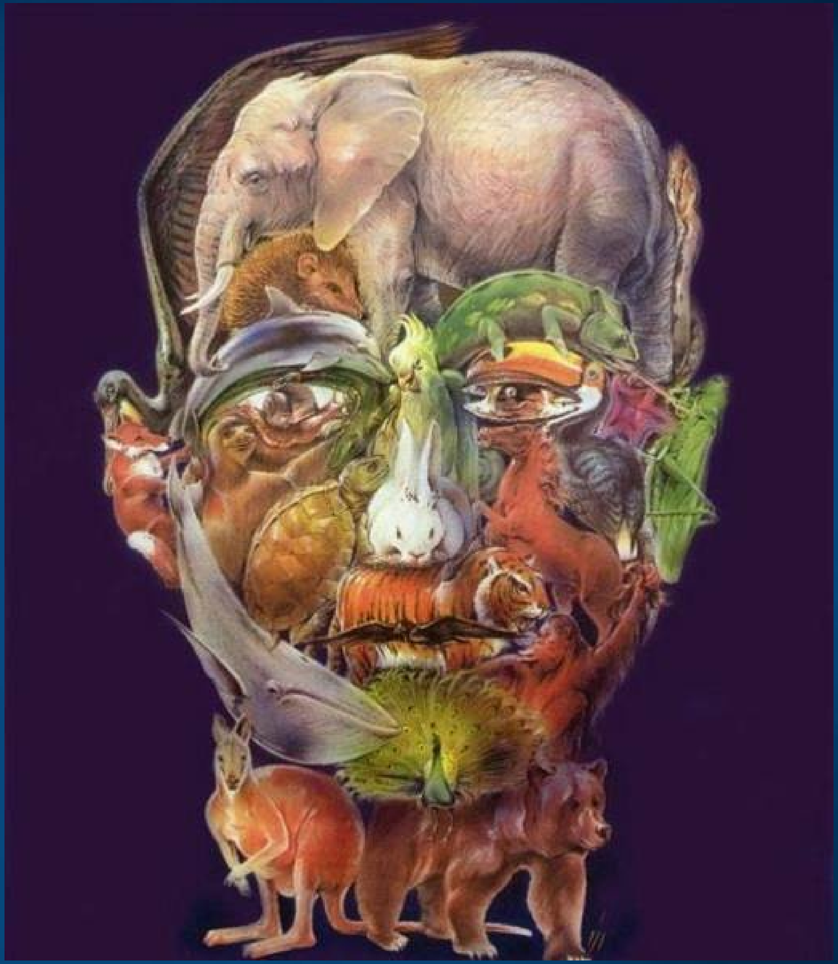
17-21.09.2017

Autism: science, therapies



Thank you for synchronization of your neurons





Google: W. Duch

=> talks, papers, lectures, Flipboard …